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XII. The Bakerian Lecture.—*Experimental Researches to determine the Density of Steam at different Temperatures, and to determine the Law of Expansion of Superheated Steam.* By William Fairbairn, *Esq.*, *F.R.S.*, *and* Thomas Tate, *Esq.*

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The object of these researches is to determine by direct experiment the law of the density and expansion of steam and other condensable vapours at all temperatures. Dumas determined with great accuracy the density of steam at 212°, but at this temperature only. Gay-Lussac and other physicists since his time have deduced the density of steam at different temperatures from a theoretical formula, which assumes that steam follows the same law of expansion and contraction as a perfectly elastic fluid.

The law which determines the relation between temperature, volume, and pressure, in the case of a perfect gas is expressed by the equation

$$\frac{VP}{V_1P_1}=\frac{\varepsilon+T}{\varepsilon+T_1}, \quad \ldots \ldots \ldots \ldots \quad (1.)$$

where V is the volume of the gas at P pressure and T temperature; V_1 the volume at P_1 pressure and T_1 temperature; ε=a constant, the value of which, according to Regnault's experiments, is for air 459. Now, assuming that steam follows the gaseous laws, we have, according to the experiments of Dumas, $V_1=1669$, the volume of steam raised from a unit of water at the temperature of 212°, and at the pressure of 14·7 lbs. per square inch. Making these substitutions in equation (1.), we get for the volume of steam from a unit of water at any other temperature T and pressure P,

$$V=1669\times14{\cdot}7\,\frac{459+T}{671\times P}$$

$$=36{\cdot}5\,\frac{459+T}{P}. \quad \ldots \ldots \ldots \ldots \quad (2.)$$

From this well-known formula all the tables of the density of steam have hitherto been deduced, on which calculations of the duty of steam-engines have been founded.

Although experimentalists have for some time questioned the truth of this theoretical formula, yet up to the present time *no reliable direct experiments* have been made to test its truth. More recently, Dr. Joule and Professor Thomson announced as the result of the application of the dynamical theory of heat, that for temperatures above 212° Fahr. there would prove to be a considerable deviation from the gaseous laws in the case of steam. In 1855, Professor Rankine gave a theoretical formula for the density of steam confirmatory of Professor Thomson's views. About the same time, and without any knowledge of Professor Rankine's formula, Mr. Tate made some experiments with the

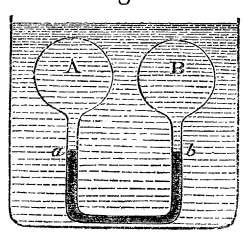
vapour of ether, which led him to conclude that at pressures somewhat above the atmospheric, the vapour of this substance does not follow the gaseous laws. Although these experiments were conducted on a scale too limited for deriving exact quantitative results, they enabled him to test the precision and delicacy of the *saturation-gauge*, which forms the leading feature of the method on which the following experiments were conducted. As yet, therefore, the results derived from the dynamical theory of heat require to be verified by direct experiments.

The general features of our method of ascertaining the density of steam consist in vaporizing a known weight of water in a large glass globe with a stem, of known capacity and devoid of air, and observing the exact temperature at which the whole of the water is just vaporized. Then, knowing the weight, volume, and temperature of the steam, its specific gravity may be calculated. In order to pursue this method with safety and with the requisite amount of accuracy, the following peculiarities of construction of the apparatus were adopted:—

First. In order to secure the thin globe from bursting, and at the same time to have it uniformly heated, it is placed in a strong closed copper steam-bath, having a thermometer and pressure-gauge attached, and a strong glass tube, closed at its exterior extremity, passing through a stuffing-box for receiving the stem of the globe. By this arrangement the glass globe is secured from bursting; for whatever may be the elasticity of the steam, the internal pressure in the globe is always exactly balanced by the external pressure in the steam-bath.

Second. When a given weight of water is vaporized in a closed vessel, devoid of air, the steam is said to be in a state of saturation so long as any portion of liquid remains in the vessel; but after all the water is vaporized, heat being still applied, the steam becomes superheated, or heated beyond the temperature just requisite for vaporizing all the water; by way of distinction, we shall call this point *the maximum temperature of saturation.* Now since we have to find *by observation* the temperature of the steam exactly at the point when the whole of the water is vaporized, the determination of this, with sufficient accuracy and delicacy, has hitherto formed the great practical difficulty attending experimental researches on the density of vapours. We have overcome this difficulty by using what may be called a *saturation gauge*, the form of which varies according to circumstances, but the principle on which it is constructed may be illustrated as follows:—

Fig. 1.



Imagine two globes, A, B, fig. 1, connected by a bent tube containing mercury and immersed in a large bath of liquid, to secure uniformity of temperature. Suppose these globes devoid of air, but containing weighed portions of water, say 20 grains in A and 30 in B. If heat be now applied to the liquid-bath so as to increase the temperature of the globes, this weighed portion of water will gradually pass into steam, and the elastic force in each globe will increase in a ratio corresponding with the temperature, but without in the least affecting the uniformity of level

of the mercury columns *a* and *b*, because the pressure on each side will be the same. But after the whole of the water in the globe A has been evaporated, this equality of pressure no longer exists, and the column *a* will rise. The pressure in B increases in the ratio for saturated steam, whilst that in A increases in the much smaller ratio of superheated steam, and hence the difference of level of the columns. The instant at which the columns begin to rise on one side and to fall on the other, is the point at which the whole of the water in A is converted into steam, and the temperature then noted is the maximum temperature of saturation. The following theoretical Table gives, approximately, the rise of the mercury column at several temperatures:—

		Increments of pressure for 1° Fahr.		
lbs.	°	for expansion.	for vaporization.	Difference.
At 4	and 152	0·012	0·222	0·21
At 7	and 176	0·022	0·32	0·30
At 15	and 213	0·044	0·60	0·56
At 20	and 228	0·060	0·80	0·74
At 61	and 295	0·16	2·00	1·84
At 74	and 308	0·20	2·22	2·02

In Plate VII. fig. 1 is an elevation, fig. 2 a section, and fig. 3 a plan of the apparatus employed in these researches for pressures varying from 15 to 70 lbs. on the square inch, or from one to five atmospheres. A is the glass globe for the reception of the weighed portion of water, drawn out into a stem about 32 inches long. The average size of the globes was $5\frac{1}{4}$ inches in diameter, or 75 cubic inches capacity; the stems were about $\frac{3}{8}$ to $\frac{7}{16}$ inches bore. B B is the copper boiler or steam-bath in which the globe was heated uniformly throughout. The copper bath is prolonged by a strong glass tube, *o o*, $1\frac{1}{4}$ inch in diameter, and hermetically sealed at the bottom: this tube is fixed to the boiler by a stuffing-box, *s s*, its upper part being trumpet-mouthed to prevent its being forced down by pressure; the joint in the stuffing-box was made by a thick ring of vulcanized india-rubber, which, with the temperatures employed in this apparatus, answered its purpose perfectly. To heat this outer tube uniformly, which, from being exposed to pressure as well as temperature, was exceedingly liable to explode, an outer oil-bath, C C, was used, made of blown glass, 20 inches long, and resting in a sand-bath, *l l*. This bath was supported on the tripod *m m m*. The copper bath was heated by a spiral coil of jets of gas, E E, and the oil-bath by a large and powerful wire-gauze lamp, *h h*, protected from draughts by a simple ring of sheet iron, *k k*. The temperature thus obtained and distributed uniformly throughout the glass tube and steam-bath by convection, was measured by the thermometer *u* in the oil, and the thermometer *t* in the steam, exposed naked, and fixed by the stuffing-box *v*. Opposite to the thermometer, *t*, is the stopcock, *p*, by which the steam is, if necessary, blown off; and on the top of the boiler is a gauge, G, of the Schæffer construction, for roughly indicating the pressure in the boiler. The two mercury columns, the outer in the tube *o o*, and the inner in the globe stem *i i*, separating the vapour and water in the steam-bath from that in the

globe, form the *saturation-gauge* to which reference has been made. So long as the steam in the globe A remains in a state of saturation, the inner column remains stationary, at a point a little above the level of the outer column, so as to balance the column of water in the steam-bath. But when, in raising the temperature, the whole of the water in A is evaporated, the steam becomes superheated, and then the pressure in A no longer balances the pressure in the steam-bath B, and the inner column of mercury rises and the outer one falls, the difference of level forming a measure of the expansion of the steam. It was found a matter of the greatest importance that the observer should not in these experiments trust to the unaided eye to determine the point at which the columns began to diverge, but that a careful series of measurements of the difference of level should be made, not only near the saturation point, but also at various temperatures of superheating; thus affording data for determining the law of expansion near the saturation point, and for estimating the maximum temperature of saturation from a point at which any error arising from the cohesion between the water and the glass, or from the retention of portions of water in the steam itself, might be eliminated. For reasons hereafter assigned, it was also found advisable to take these readings of the levels of the columns rather in a descending than in an ascending series of temperatures.

To read the column levels with rapidity and facility, seeing that they could not be approached within six or eight inches, a simple form of cathetometer was devised, sufficiently accurate for the purpose, and much more convenient than the complicated French instrument sometimes employed for this purpose. This cathetometer is shown in elevation, in Plate VIII. fig. 2; *a* is a heavy iron base resting on three levelling screws; into this is screwed firmly the planed iron stem *c c*, and adjusted by the levelling screws in a vertical position; on the stem slides a brass block, *b*, carrying a small telescope, *t t*, with sight wires, and fixed by a thumb-screw behind. Fig. 3 shows a part of the stem, *c c*, with the graduation into inches and tenths, the block *b* and vernier *v* moving with the telescope, by which the levels of the columns were read off to hundredths of an inch. In Plate VII. fig. 1, *f f* shows the position of the cathetometer in the experiments, on its iron base or pedestal, *g*.

The steps in the process for determining the specific gravity of steam by this apparatus were as follows:—

A glass globule, of a size to contain as nearly as might be the required quantity of water for vaporization, was selected from a series similar in form to those shown in fig. 6, Plate VIII. In order to avoid the collision produced by the bursting of a sealed globule of water, as in GAY-LUSSAC'S method, these globules had open stems, and after being filled with water were immersed hot in a cup of mercury (fig. 7), so that in cooling the mercury should rise and fill in part the capillary stem. The weight (w_1) of the cup, mercury and globule, all perfectly dry, was first ascertained by means of a delicate balance; the globule being then filled with water, the stem plunged in the mercury, and the surface of the mercury being dried, the weight (w_2) of the whole was determined. In this state the cup of mercury was transferred, and the globule passed into the large

globe, in which a Torricellian vacuum had been formed. Here the weight of water introduced $=w=w_2-w_1$.

To form the Torricellian vacuum, the globe, filled with warm dry mercury, was heated upon a sand-bath until the mercury boiled; the stem was then filled with dry mercury and the globe inverted, with its stem inserted in a basin of mercury. The globule was then introduced into the stem, and allowed to ascend through the mercury column into the globe. In order to transfer the globe from the basin to its place in the steam-bath, a cap, *k* (Plate VIII. figs. 4 & 5), filled with mercury, was suspended from the stem by an india-rubber strap, a platinum wire being placed between the cap and globe-stem to ensure free passage for the mercury. The cover of the boiler, B B (Plate VII.), being then taken off, and the outer tube, *o o*, partially filled with dry mercury, the globe was raised and inserted into its place, resting on a tripod in the boiler, as shown in the diagram. The cover was then fixed with a flax and red-lead joint, and the cock *p* connected with a single barrel air-pump; exhaustion was effected so that the columns in the globe-stem and outer tube came nearly to a level; the air-pump was removed, and a portion of water allowed to enter through the cock. The gas-lights were then kindled, and until the water reached the boiling-point, the columns were maintained in position by the air-pump. The object of this, it will be seen, was to prevent any water passing round from the boiler to the globe. After boiling for a time the cock *p* was closed, and the process of vaporization went on simultaneously in the bath and globe, the temperature being kept sufficiently high in the oil-bath C C to maintain the water in the outer tube in a state of ebullition.

When all the parts of the globe have attained the same temperature as the steam in the bath, the mercury in the stem of the globe will stand a little above the mercury in the outer tube C C, the difference, *a b*, balancing the column of water, *b c*, and possibly the pressure of any air left in the steam-bath. The temperature of the baths is slowly and uniformly increased until the temperature of the vapour in the globe is considerably above the maximum temperature of saturation: after having been maintained for a considerable period at this temperature, the levels of the columns were observed; then, the temperature being allowed to sink some degrees, the operation was repeated, and the temperature again reduced until the columns became stationary, indicating saturated steam in the globe as well as the bath. The readings of a series of file marks on the globe-stem were taken at the same time, by which the capacity of the globe in each position of the mercury column could be calculated. All the elements were thus ascertained for calculating the density of the steam.

Let w be put for the weight of distilled water, at a temperature of 39°·1 Fahr., filling the globe to the point at which the mercury columns stood at the maximum temperature of saturation; let w be the weight of water vaporized; $\mathrm{v}=$ the specific volume of the steam, or the number of times the volume of steam exceeds the volume of the water from which it is raised; then

$$\mathrm{v}=\frac{\mathrm{w}}{w}. \qquad (3.)$$

By at once superheating the steam in the globe and then slowly reducing the temperature until the maximum temperature of saturation is reached, we secure the following advantages:—The cohesion of the water to the surface of glass being once overcome, that force of cohesion, it may be presumed, cannot be regained until the glass again becomes wet, which can only occur on condensation, that is, by the reduction of the temperature below that which corresponds to the maximum temperature of saturation. Moreover the observation of the columns at different temperatures of superheating, not only supplies us with data for determining the law of expansion of the superheated steam, but also data of verification or correction, as the case may be, of the point of maximum saturation determined by direct observation.

The results of the experiments show, *first*, that the density of saturated steam at all temperatures, above as well as below 212°, is invariably greater than that which is derived from the gaseous laws; *second*, that the law of expansion of a perfectly elastic fluid does not hold strictly true for superheated steam. At the maximum temperature of saturation, and for some degrees above it, the rate of expansion of the steam greatly exceeds that of a perfect gas.

SECTION I.—*Experiments at Pressures varying from fifteen to seventy pounds per square inch.*

In these experiments the thermometers were, it will be seen, exposed naked in the steam of the copper boiler, and this method offered the great advantage of rapidity in the indications of change of temperature round the globe, and enabled the observers, by constant and vigilant attention to the regulation of the supply of gas, to keep the temperature in the copper bath as nearly as possible uniform. But the thermometers, from exposure to pressure, require a correction. For this purpose the following experiments were obtained with simple water pressure.

Experiment 1.—*Thermometer* A.

Pounds pressure per square inch.	Temperature indicated.	Rise from pressure.
0	48°·2	——
20	48·8	0·6
40	49·1	0·9
60	49·5	1·3

Here the mean rise is 0°·022 for each pound of pressure above the atmosphere.

Experiment 2.—*Thermometer* B.

Pounds pressure per square inch.	Temperature indicated.	Rise from pressure.
0	198°·0	——
50	198·9	0·9

Here the rise is 0°·018 per pound pressure per square inch.

In the Tables of the experiments the temperatures are given as registered. In the summaries they are given reduced for pressure in the proportions above stated. No correction has been made to reduce the temperatures from the mercurial to the air-thermometer.

Capacity of Globes.

First. Globe A.—Water introduced =18009 grains at 63° FAHR. This corrected to 39°·1=18033 grains. Hence the capacity at the several file marks,—

Graduation:	First file mark	=18033 grains.
	Second file mark	=18159·2 grains.
	Third file mark	=18285·4 grains.
	Fourth file mark	=18411·6 grains.
	Fifth file mark	=18537·8 grains.

Second. Globe B.—Water introduced =17642 grains at 62°·5. Corrected to 39°·1=17663 grains.

Graduation:	First file mark	=17663 grains.
	Second file mark	=18420·4 grains.
	Third file mark	=18672·9 grains.
	Fourth file mark	=18925·3 grains.
	Fifth file mark	=19177·7 grains.

Third. Globe C.—Capacity taken with mercury equivalent to 18025 grains of water at 62° FAHR. Corrected to 39°·1=18046 grains.

Graduation:	First file mark	=18046 grains.
	Second file mark	=18298·4 grains.
	Third file mark	=18550·8 grains.
	Fourth file mark	=18803·2 grains.
	Fifth file mark	=18929·4 grains.
	Sixth file mark	=19055·6 grains.
	Seventh file mark	=19181·8 grains.

The following Tables give the results of the experiments between the ordinary atmospheric pressure and 60 lbs. per square inch. The first Table gives the observed results in full in each case, and the second gives a summary in which the column levels at the same temperature are averaged and corrections made for pressure in the thermometer bulb, expansion of mercury, &c.

Time.—The time between each reading is given as an indication of the reliability of the determinations of the column levels; changes of temperature could be made with great rapidity in the steam-bath, even without blowing off any steam, by lowering the gas-lights; but it required ten to fifteen minutes before the temperature of the glass globe had become uniform with the surrounding steam, and the columns had become stationary under the new temperature. When this was found to have taken place, a

series of readings was taken at intervals of three to five minutes, to obtain a reliable average, and the temperature again reduced.

Thermometers.—It was found necessary to maintain the temperature of the oil-bath considerably higher than that in the steam-bath, in order to make up for the radiation from the exposed portion of the tube and for the great retardation to the passage of the heat offered by the thick outer glass tube. The rule followed was to sustain such a temperature as would cause a gentle ebullition in the glass tube, trusting to the rapid convection of the water to secure a uniform temperature. No appreciable error could arise from this source from the smallness of the volume of steam in the globe-stem, and it was found in practice that a deposition of moisture almost immediately followed any cessation of the ebullition in the outer tube.

For another reason the necessity of a higher temperature in the oil-bath became a source of serious difficulty. The difference between the temperature of the water and oil required to be constantly increased as the temperature and pressure became higher, because the radiation increased in a higher ratio than could be prevented by the use of flannel coats, and a point was at last reached at which the unequal expansion of the thick glass tube on its cooler and warmer side, combined with the great pressure in its interior, caused a rupture attended by a dangerous explosion of great violence. Twice with glass tubes, which should have borne a pressure of 500 lbs., and each time under a pressure of only about 70 lbs. per square inch, an explosion occurred. In each case the fracture began in the bottom or closed end of the tube (unfortunately thickened by the glass-blower), as was evidenced by the boiler being lifted vertically from its seating, although the entire disruption of the tube immediately followed in the course of the explosion.

Temperature reduced for pressure.—This column is calculated from the observed temperatures according to the ratio arrived at in the experiments with water pressure. The thermometers were made expressly for these experiments at the Kew Observatory, and the graduation was accurate within the limits of errors of observation.

Capacity, in grains of water.—This column has been calculated from the readings on the cathetometer of the graduation marks, taken during each experiment. The capacity of the globe it is evident decreased as the inner column rose.

Difference of level has been corrected to 32° FAHR., at which temperature one atmosphere of pressure is assumed to be equivalent to 29·9218 inches of mercury.

Pressure of saturated steam, calculated from the experiments of M. REGNAULT.—This is evidently the pressure of the steam in the steam-bath; and if we deduct from this the column of mercury in the globe-stem which this pressure balances, we arrive at the pressure of the superheated steam in the glass globe, given in the next column.

Specific volume of the steam, obtained by dividing the capacity of the globe at each temperature by the quantity of water introduced.

In these experiments we were ably assisted by Mr. W. C. UNWIN; and we have much pleasure in stating that to his untiring zeal and superior skill in manipulation we are indebted for many important results.

Experiment 1.—Globe C. Thermometer A. March 8, 1859.
Weight of water introduced =20·126 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
2 25	253	264	29·44	19·66	9·78	
2 30	253	.....	29·45	19·69	9·76	
2 40	253	.....	29·45	19·62	9·83	
2 45	253	.....	29·47	19·64	9·83	
2 50	253	.....	29·45	19·66	9·79	
2 55	253	.....	29·48	19·69	9·79	
3 18	251	262	28·13	20·24	7·89	
3 22	251	.....	28·10	20·26	7·84	
3 26	251	.....	28·00	20·18	7·82	
3 30	251	.....	28·16	20·15	8·01	
3 37	251	264	28·17	20·16	8·01	
3 42	251	.....	28·19	20·13	8·06	
4 0	249	260	26·72	20·63	6·09	
4 12	249	.....	26·58	20·68	5·90	
4 17	249	.....	26·59	20·63	5·96	
4 21	249	259	26·72	20·54	6·18	
4 25	249	.....	26·60	20·53	6·07	
4 30	249	.....	26·58	20·59	5·99	
4 55	246	258	24·62	21·24	3·38	
5 3	246	.....	24·70	21·16	3·54	Steam began to condense in globe-stem at $5^h\ 10^m$.
5 20	246	264	24·61	21·24	3·37	
5 23	246	.....	24·77	21·19	3·58	
5 26	246	.....	24·75	21·22	3·53	
5 32	244	280	23·71	21·57	2·14	
5 38	244	.....	23·62	21·60	2·02	
5 42	244	.....	23·46	21·60	1·86	
5 46	244	.....	23·58	21·52	2·06	
5 50	244	282	23·70	21·53	2·17	
6 10	243	282	23·36	21·67	1·69	
6 12	243	.....	23·30	21·69	1·61	
6 15	243	.....	23·30	21·68	1·62	
6 17	243	.....	23·38	21·64	1·74	
6 20	243	.....	23·31	21·65	1·66	
6 26	242	280	23·20	21·69	1·51	
6 30	242	.....	23·14	21·70	1·44	
6 35	242	.....	23·10	21·72	1·38	
6 40	242	.....	22·97	21·75	1·22	
6 45	242	.....	23·11	21·68	1·43	
6 50	242	268	23·16	21·68	1·48	
6 55	240	268	22·99	21·72	1·27	
7 0	240	.....	22·99	21·72	1·24	Condensation visible in globe-stem.

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
240	22·99	1·26	2	239·79	18938·2	1·24	.....	49·43	49·43	943·12
242	23·11	1·41	6	241·76	18929·8	1·38	0·14	52·53	52·39	942·72
243	23·33	1·67	5	242·75	18922·4	1·64	0·40	53·47	53·07	942·32
244	23·62	2·05	6	243·74	18908·9	2·01	0·77	54·43	53·66	941·67
246	24·69	3·48	5	245·72	18857·4	3·41	2·17	56·38	54·21	939·11
249	26·63	6·03	6	248·69	18771·4	5·90	4·66	59·42	54·76	934·86
251	28·12	7·93	6	250·67	18681·3	7·76	6·52	61·52	55·00	930·41
253	29·46	9·80	6	252·65	18609·8	9·59	8·35	63·68	55·33	926·91

Experiment 2.—Globe B. Thermometer A. March 3, 1859.

Weight of water introduced =21·193 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
4 20	254	290	29·42	20·52	8·90	
4 25	254	290	29·54	20·36	9·18	
4 30	254	290	29·54	20·32	9·22	
4 37	254	290	29·27	20·47	8·80	
4 45	254	290	29·56	20·34	9·22	
4 55	251	284	27·78	21·11		
5 3	251	284	27·53	21·14	6·39	
5 13	251	284	27·58	21·03	6·55	
5 15	251	284	27·50	21·16	6·34	
5 18	251	285	27·55	21·07	6·48	
5 25	251	285	27·32	21·19	6·13	
5 30	251	285	27·54	21·03	6·51	
6 0	248	273	25·41	21·80	3·61	
6 5	248	.....	25·40	21·81	3·59	
6 10	248	.....	25·61	21·66	3·95	
6 17	248	.....	25·26	21·87	3·39	
6 20	248	266	25·61	21·54	4·07	
6 35	245	278	23·94	22·13	1·81	
6 45	245	.....	24·02	22·08	1·97	
6 50	245	.....	23·98	22·06	1·92	No water visible in globe-stem.
7 5	245	.....	24·04	22·04	2·00	
7 17	245	.....	24·12	22·13	1·99	
7 22	245	262	23·98	22·02	1·96	
7 32	243	.....	23·73	22·14	1·59	
7 35	243	.....	23·69	22·12	1·57	
7 42	243	.....	23·74	22·12	1·62	No water visible in stem.
7 50	243	254	23·74	22·10	1·64	
7 57	241	.....	23·57	22·11	1·46	
8 5	241	.....	23·57	22·13	1·44	
8 20	244	.....	23·81	22·12	1·69	
8 25	244	.....	23·86	22·12	1·74	
8 30	245	260	24·10	22·06	2·04	
8 35	245	.....	24·11	22·06	2·05	
8 50	246	260	24·60	21·84	2·76	
9 0	246	.....	24·59	21·87	2·72	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for the expansion of glass.
°	inches.	inches.		°		inches.	inches.			
241	23·57	1·45	2	240·78	19200·3	1·42	.....	50·98	50·98	908·03
243	23·70	1·57	5	242·74	19198·8	1·54	0·12	53·47	53·35	907·98
244	23·83	1·71	2	243·72	19186·6	1·67	0·25	54·43	54·18	907·41
245	24·04	1·97	8	244·71	19177·0	1·93	0·51	55·40	54·89	906·94
246	24·59	2·74	2	245·70	19147·9	2·69	1·27	56·38	55·11	905·59
248	25·62	3·89	5	247·70	19097·8	3·81	2·39	58·41	56·02	903·25
251	27·54	6·44	7	250·67	18998·9	6·31	4·99	61·52	56·53	898·61
254	29·46	9·06	5	253·63	18893·2	8·87	7·45	64·69	57·24	893·64

Experiment 3.—Globe C. Thermometer A. December 8, 1858.
Weight of water introduced =21·175.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
12 0	.....	.....	.....	.....	.....	Lamps lighted.
1 5	212	.....	30·33	20·30	10·03	Steam blowing off.
1 40	211·6	226	24·75	22·72	2·03	Steam-cock shut.
3 50	252	256	29·52	21·10	8·42	The differences in the cathetometer readings arise from the oscillation of the columns, which had to be read consecutively and not contemporaneously; partly perhaps from the obscuring of the real level in the outer tube by steam bubbles. These differences, however, are not great.
3 55	252	256	29·50	21·16	8·34	
4 0	252	255	29·65	21·14	8·51	
4 7	253	256	30·13	20·93	9·20	
4 18	253	265	30·16	21·00	9·16	
4 22	253	265	30·15	21·00	9·15	
4 37	251	262	28·94	21·36	7·58	
4 42	251	262	28·92	21·42	7·50	
4 50	250	260	28·50	21·68	6·82	
5 0	250	263	28·53	21·68	6·85	
5 10	249	262	27·98	21·73	6·25	
5 30	248	255	27·57	21·85	5·72	
5 50	247	268	27·09	21·99	5·10	
6 10	246	275	26·68	22·14	4·54	
6 25	245	272	26·43	22·25	4·18	
6 35	244	260	26·05	22·35	3·70	
6 40	244	257	26·22	22·32	3·90	
6 50	244	260	26·18	22·32	3·86	
7 40	244	265	26·20	22·31	3·89	
7 55	242	268	25·58	22·48	3·10	
8 0	242	268	25·56	22·50	3·06	
8 10	240	271	25·16	22·62	2·54	
8 20	242	271	25·56	22·52	3·04	
8 35	244	273	26·13	22·32	3·81	
8 45	246	274	27·01	22·15	4·86	
9 10	250	274	28·54	21·54	7·00	
9 30	252	277	29·79	21·12	8·67	
10 0	246	276	26·66	22·15	4·51	
10 8	245	274	26·42	22·22	4·20	
10 11	245	274	26·45	22·22	4·23	
10 20	247	.....	27·10	21·99	5·11	
10 23	247	.....	27·13	22·02	5·11	
10 30	244	276	26·14	22·34	3·80	
10 34	244	.....	26·18	22·33	3·85	
10 50	243	.....	25·94	22·45	3·49	
11 0	243	.....	25·90	22·35	3·55	
11 10	240	.....	25·28	22·56	2·72	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
240	25·22	2·63	2	239·79	18856·6	2·58	.....	49·43	49·43	892·54
242	25·56	3·07	3	241·77	18840·5	3·01	0·43	52·53	52·10	891·74
243	25·92	3·34	2	242·76	18823·5	3·28	0·70	53·47	52·77	890·92
244	26·16	3·83	7	243·75	18812·1	3·76	1·18	54·43	53·25	890·40
245	26·43	4·19	2	244·74	18798·9	4·11	1·53	55·40	53·87	889·86
246	26·78	4·64	3	245·73	18780·1	4·55	1·97	56·38	54·41	888·98
247	27·11	5·11	3	246·72	18762·4	5·01	2·43	57·36	54·93	888·14
250	28·52	6·89	3	247·69	18686·7	6·75	4·17	60·52	56·35	884·60
252	29·61	8·48	4	251·66	18628·1	8·30	5·72	62·65	56·91	881·83
253	30·15	9·17	3	252·65	18599·1	8·98	6·40	63·68	57·28	880·46

Experiment 4.—Globe B. Thermometer A. March 11, 1859.

Weight of water introduced = 25·35 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h. m	°	°	inches.	inches.	inches.	
2 5	264	294	29·43	19·86	9·57	A more abundant command of heat was obtained in this than in preceding experiments.
2 10	264	.....	29·34	19·90	9·44	
2 15	264	.....	29·41	19·83	9·58	
2 20	264	.....	29·33	19·86	9·47	
2 25	264	285	29·37	19·81	9·56	
2 40	264	.....	29·30	19·86	9·44	
2 45	264	291	29·34	19·86	9·48	
2 51	261	294	27·30	20·65		
3 2	261	.....	26·90	20·71	6·19	
3 5	261	.....	27·02	20·66	6·36	
3 8	261	.....	26·98	20·70	6·28	
3 14	261	.....	26·95	20·71	6·24	
3 17	261	.....	26·89	20·71	6·18	
3 22	261	.....	26·94	20·71	6·23	
3 27	261	.....	26·90	20·71	6·19	
3 35	261	286	26·91	20·71	6·20	
4 0	259	.....	25·57	21·18	4·39	Interrupted for a short time.
4 35	259	.....	25·67	21·10	4·57	
4 43	259	290	25·50	21·12	4·38	
4 55	259	.....	25·54	21·18	4·36	
4 58	259	.....	25·54	21·14	4·40	
5 3	259	.....	25·52	21·11	4·41	
5 16	257	290	24·16	21·54	2·62	
5 20	257	.....	24·16	21·55	2·61	
5 25	257	.....	24·25	21·51	2·74	
5 30	257	.....	24·16	21·54	2·62	
5 35	257	.....	24·16	21·53	2·63	
5 40	257	300	24·16	21·51	2·63	
5 50	255	.....	23·35	21·76	1·59	
6 0	255	.....	23·32	21·71	1·61	
6 5	255	.....	23·35	21·71	1·64	
6 10	255	.....	23·36	21·70	1·66	
6 20	253	.....	23·14	21·79	1·35	
6 23	253	.....	23·14	21·79	1·35	
6 27	253	.....	23·14	21·80	1·34	
6 30	253	.....	23·17	21·79	1·38	
6 35	251	.....	23·16	21·78	1·38	
6 40	251	.....	23·12	21·77	1·35	
6 45	251	.....	23·14	21·79	1·35	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
251	23·14	1·36	3	250·66	19206·4	1·34	.....	61·52	61·52	759·44
253	23·15	1·36	4	252·64	19206·4	1·34	.....	63·86	63·86	759·44
255	23·34	1·62	4	254·62	19196·4	1·60	0·26	65·89	65·63	759·06
257	24·17	2·64	6	256·60	19154·1	2·59	1·25	68·17	66·92	757·45
259	25·56	4·42	6	258·58	19082·5	4·32	2·98	70·52	67·54	754·62
261	26·93	6·23	8	260·54	19012·3	6·10	4·76	72·90	68·14	751·87
264	29·37	9·52	7	263·51	18878·0	9·30	7·96	76·64	68·68	746·70

Experiment 5.—Globe C. Thermometer A. December 10, 1858.

Weight of water in globe 29·145 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
1 0	.....	.....	.....	.....	.....	Lamps lighted.
5 25	273·2	300	32·22	20·18	12·04	
6 8	268	290	28·87	21·32	7·55	
6 14	268	289	28·55	21·41	7·14	
6 20	268	288	28·86	21·34	7·52	
6 43	264	286	26·60	22·10	4·50	
6 55	262	284	26·04	22·29	3·75	
7 0	262	284	26·11	22·27	3·84	
7 8	260	283				
7 15	260	285	25·48	22·44	3·04	
7 25	260	288	25·55	22·42	3·13	
7 42	256	293	24·77	22·68	2·09	
7 55	256	293	24·51	22·62	1·89	
9 0	273·2	315	32·31	20·08	12 23	
9 7	270	315	29·73	20·99	8·74	
9 12	268	315	28·41	21·39	7·02	
9 16	266	315	27·56	21·72	5·84	
9 22	264	310	26·51	22·06	4·45	
9 26	262	308	25·82	22·27	3·55	
9 33	260	.....	25·40	22·40	3·00	
9 38	260	.....	25·67	22·32	3·55	
9 58	264	.....	26·80	21·95	4·85	
10 10	266	300	27·80	21·55	6·25	
10 15	266	.....	27·64	21·62	6·02	
10 30	268	297	28·86	21·22	7·64	
10 35	268	.....	28·86	21·29	7·57	
11 7	273·2	310	32·35	19·94	12·41	

Summary of Column Determinations.

Mercurial thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
	inches.	inches.				inches.	inches.			
256°	24·64	1·99	2	255°·61	18876·0	1·95	.....	67·03	67·03	649·24
260	25·52	3·18	4	259·56	18834·4	3·12	1·17	71·71	70·54	647·82
262	25·99	3·71	3	261·53	18814·1	3·63	1·68	74·09	72·41	647·65
264	26·63	4·60	3	263·50	18781·9	4·50	2·55	76·64	74·09	646·08
268	28·73	7·40	6	267·45	18666·3	7·23	5·28	81·84	75·56	642·12
270	29·73	8·74	1	269·41	18612·6	8·54	6·59	84·53	77·94	640·28
273·2	32·29	12·23	3	272·56	18475·1	11·95	10·00	89·01	79·01	635·59

Experiment 6.—Globe C. Thermometer A. March 12, 1859.
Weight of water introduced = 29·95 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
2 25	279	310	31·60	17·45	14·15	Lamps lighted at 11h 30m.
2 30	279	.....	31·59	17·40	14·19	
2 32	279	.....	31·60	17·35	14·25	
2 35	279	.....	31·62	17·46	14·16	
2 37	279	.....	31·64	17·36	14·28	
2 50	275	294	28·34	18·75	9·59	
3 5	275	.....	28·29	18·71	9·58	
3 8	275	.....	28·33	18·70	9·63	
3 15	275	.....	28·36	18·68	9·68	
3 16	275	.....	28·34	18·73	9·61	
3 19	275	.....	28·35	18·68	9·67	
3 22	275	.....	28·40	18·69	9·71	
3 30	271	290	24·71	19·96	4·75	
3 35	271	.....	24·67	19·95	4·72	
3 45	271	.....	24·78	19·78	5·00	No moisture could be detected in stem.
3 50	271	.....	24·78	19·78	5·00	
3 55	271	.....	24·91	19·78	5·13	
4 4	271	.....	24·74	19·83	4·91	
4 15	267	.....	22·38	20·52	1·86	
4 18	267	.....	22·30	20·57	1·73	
4 21	267	.....	22·38	20·52	1·86	
4 24	267	.....	22·37	20·50	1·87	
4 25	266	.....	22·28	20·53	1·75	
4 26	266	.....	22·26	20·56	1·70	
4 27	266	.....	22·26	20·53	1·73	
4 29	266	.....	22·26	20·51	1·75	
4 35	265	.....	22·11	20·58	1·53	
4 36	265	.....	22·18	20·55	1·63	
4 37	265	.....	22·16	20·54	1·62	
4 39	263	.....	22·02	20·58	1·44	Condensation became apparent in the stem at this temperature.
4 40	263	.....	.....	.....	.....	
4 43	263	.....	22·10	20·60	1·50	
4 45	263	.....	22·03	20·57	1·46	
4 47	263	.....	22·01	20·57	1·44	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
263	22·04	1·46	4	262·52	18979	1·43	.....	75·37	75·37	635·30
265	22·16	1·60	3	264·49	18974	1·56	0·13	77·94	77·81	635·13
266	22·26	1·73	4	265·47	18970	1·69	0·26	79·24	78·98	635·00
267	22·36	1·83	4	266·46	18966	1·79	0·36	80·54	80·18	634·87
268	22·77	2·37	2	267·45	18948	2·32	0·89	81·84	80·95	634·28
271	24·76	4·95	6	270·40	18853	4·83	3·40	85·92	82·52	631·15
275	28·34	9·64	7	274·34	18657	9·41	7·98	91·62	83·64	624·62
279	31·61	14·19	5	278·27	18489	13·84	12·41	97·61	85·20	619·03

Experiment 7.—Globe B. Thermometer A. March 15, 1859.

Weight of water introduced = 31·730 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m			inches.	inches.	inches.	
2 20	279°	320°	31·64	20·16	11·48	Lamps lighted at 12 o'clock.
2 30	279	.....	31·63	20·14	11·49	
2 33	279	.....	31·74	20·16	11·58	
2 35	279	.....	31·70	20·14	11·56	
2 37	279	.....	31·58	20·14	11·44	
2 50	275	300	28·18	21·40	6·78	
2 54	275	.....	28·38	21·33	7·05	
2 57	275	.....	28·20	21·43	6·77	
3 0	275	.....	28·30	21·38	6·92	
3 7	275	300	28·26	21·38	6·88	
3 15	275	.....	28·36	21·41	6·95	
3 25	273	.....	26·38	22·02	4·36	
3 30	273	.....	26·30	22·02	4·28	
3 35	273	.....	26·45	22·00	4·45	
3 38	273	.....	26·36	22·01	4·35	
3 40	273	.....	26·40	22·01	4·39	
3 41	273	.....	26·38	22·02	4·36	
3 42	273	.....	26·41	22·02	4·39	
3 50	271	301	24·89	22·47	2·42	
3 56	271	.....	25·04	22·48	2·56	
4 0	271	.....	24·99	22·45	2·54	
4 3	271	.....	25·09	22·44	2·65	
4 4	271	.....	25·06	22·46	2·60	
4 6	271	.....	24·95	22·50	2·45	
4 10	271	.....	25·08	22·46	2·62	
4 55	267	310	23·93	22·79	1·14	
4 56	267	.....	23·95	22·79	1·16	
4 57	267	.....	23·98	22·77	1·21	
4 58	267	.....	23·95	22·79	1·16	
5 0	265	.....	23·81	22·80	1·01	
5 3	265	.....	23·89	22·78	1·11	
5 5	265	.....	23·95	22·78	1·17	
5 7	265	.....	23·89	22·75	1·14	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
	inches.	inches.				inches.	inches.			
265°	23·89	1·11	4	264°·49	19168·5	1·09	.....	77·94	77·94	605·65
267	23·95	1·19	4	266·46	19165·5	1·16	0·07	80·54	80·47	605·55
271	25·01	2·55	7	270·40	19111·2	2·50	1·41	85·92	84·51	603·90
273	26·38	4·37	7	272·36	19041·1	4·26	3·17	88·71	85·54	601·71
275	28·26	6·93	7	274·34	18934·5	6·76	5·67	91·62	85·95	598·34
279	31·65	11·51	5	278·27	18731·2	11·23	10·14	97·605	87·465	591·95

Experiment 8.—Globe A. Thermometer B. October 11, 1859.

Weight of water introduced = 31·58 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
4 30	282	301	22·72	12·32	10·40	Premature.
4 33	282	301	22·74	12·30	10·44	Premature.
4 37	282	301	22·68	12·30	10·38	Globe-stem dry.
4 43	282	300	22·66	12·35	10·31	
4 53	278	300	19·00	13·70	5·30	
5 0	278	297	19·01	13·67	5·34	
5 5	278	297	18·91	13·60	5·31	
5 10	278	297	18·90	13·63	5·27	
5 15	278	297	18·85	13·62	5·23	On sinking to 276°, moisture became visible in stem at $5^h\ 25^m$, the temperature was therefore raised again.
5 55	278	307	19·00	13·70	5·30	
5 58	278	.....	18·85	13·70	5·15	
6 0	278	304	18·85	13·74	5·11	
6 8	276	.....	17·47	14·16	3·31	A trace of moisture perceptible.
6 15	276	.....	17·45	14·17	3·28	
6 17	276	308	17·40	14·21	3·19	
6 19	276	.....	17·50	14·17	3·33	
6 23	276	.....	17·40	14·11	3·29	Moisture still preserved.
6 33	274	.....	16·66	14·34	2·32	
6 35	274	.....	16·60	14·34	2·26	
6 40	274	.....	16·80	14·35	2·45	
6 45	274	.....	16·70	14·28	2·42	
6 50	274	.....	16·70	14·33	2·37	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity, of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
274	16·69	2·36	5	273·48	18406·7	2·31	.....	90·35	90·35	584·44
276	17·44	3·28	5	275·46	18372·9	3·20	0·89	93·29	92·40	583·37
278	18·92	5·25	8	277·43	18306·1	5·13	2·82	96·30	93·48	581·26
282	22·67	10·34	2	281·38	18118·1	10·09	7·78	102·56	94·78	574·00

Experiment 9.—Globe A. Thermometer B. October 14, 1859.

Weight of water introduced = 34·01 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m			inches.	inches.	inches.	
4 15	289°	318°	24·13	12·12	12·01	Lamps lighted at 2 o'clock. Water boiling at 3 o'clock.
4 17	289	.....	24·30	12·10	12·20	
4 20	289	.....	24·22	12·12	12·10	
4 25	289	.....	24·29	12·12	12·17	
4 27	289	.....	24·20	12·07	12·13	
4 30	289	316	24·26	12·06	12·20	
4 47	285	314	20·70	13·63	7·07	
4 49	285	.....	20·75	13·64	7·11	
4 51	285	.....	20·65	13·63	7·02	
4 53	285	.....	20·65	13·60	7·05	
4 56	285	.....	20·66	13·60	7·06	
5 0	285	315	20·72	13·64	7·08	
5 5	283	.....	18·82	14·24	4·58	
5 10	283	.....	18·85	14·22	4·63	
5 14	283	.....	18·84	14·25	4·59	
5 17	283	.....	18·90	14·25	4·65	
5 19	283	.....	18·90	14·26	4·64	
5 21	283	.....	18·86	14·29	4·57	
5 30	278	.....	16·65	15·10	1·55	
5 33	278	.....	16·64	15·10	1·54	
5 35	278	.....	16·66	15·09	1·57	
5 40	274	.....	16·44	15·11	1·33	
5 42	274	.....	16·50	15·13	1·37	
5 45	274	.....	16·45	15·10	1·35	
5 50	274	.....	16·43	15·05	1·38	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity, of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam, corrected for expansion of glass.
	inches.	inches.				inches.	inches.			
289°	24·23	12·13	6	288°·25	18040·1	11·78	10·45	114·24	103·79	531·96
285	20·69	7·06	6	284·32	18235·4	6·86	5·53	107·44	101·91	537·68
283	18·86	4·61	6	282·34	18319·7	4·48	3·15	104·14	100·99	540·17
278	16·65	1·55	3	277·43	18415·4	1·51	0·18	96·30	96·12	542·91
274	16·45	1·36	4	273·48	18423·8	1·33	.....	90·35	90·35	543·17

Experiment 10.—Globe B. Thermometer A. December 14, 1858.

Weight of water introduced = 37·58 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
12 45	285	316	.....	19·50	.....	
2 15	285	304	30·20	22·63	7·57	
2 20	285	307	30·73	22·42	8·31	Probably erroneous.
2 30	285	330	30·20	22·64	7·56	
2 40	285	325	29·53	23·01	6·52	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.
	inches.	inches.				inches.	inches.
Max. desc.	24·33 ?	2·50 ?	.....	.....	18930	2·45 ?	.....
285°	29·98	7·21	4	284·16	18872	7·04	4·59

After obtaining these determinations, and whilst the experiment was incomplete, the oil-bath cracked at the bottom and stayed further progress. In consequence of having these vessels so deep, difficulty was found in getting them blown, and we had to be content with such as could be obtained. These were very thick at the bottom, where the heat was greatest and danger most to be apprehended, and in consequence at the higher pressures they became a fertile source of annoyance.

Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
.....	.....	514·98
107·17	102·58	503·60

Experiment 11.—Globe B. Thermometer A. March 19, 1859.

Weight of water introduced = 38·745 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
2 25	291	320	31·04	19·40	11·64	Lamps lighted at $11^h\ 45^m$.
2 28	291	.....	31·02	19·42	11·60	
2 30	291	.....	30·97	19·44	11·53	
2 40	287	.....	26·85	20·78	6·07	
2 45	287	.....	27·00	20·85	6·15	
2 53	287	.....	26·72	20·78	5·94	
3 0	287	.....	26·74	20·77	5·97	
3 20	285	320	24·90	21·34	3·56	
3 25	285	.....	24·80	21·33	3·47	
3 30	285	.....	24·85	21·34	3·51	
3 35	285	.....	24·85	21·37	3·48	
3 50	284	.....	24·20	21·59	2·61	
3 55	284	.....	24·15	21·56	2·59	
4 0	284	.....	24·19	21·56	2·63	
4 4	284	.....	24·13	21·58	2·55	
4 10	284	.....	24·20	21·52	2·68	
4 17	283	.....	23·74	21·70	2·04	
4 30	283	.....	23·80	21·66	2·14	
4 34	283	.....	23·75	21·65	2·10	
4 40	283	.....	23·79	21·64	2·15	
4 50	282	.....	23·46	21·75	1·71	
4 57	282	.....	23·46	21·72	1·74	
5 3	282	.....	23·50	21·76	1·74	
5 8	281	316	23·10	21·79	1·31	
5 13	281	.....	23·37	21·71	1·66	
5 20	281	.....	23·41	21·74	1·67	
5 23	281	.....	23·38	21·76	1·62	
5 30	279	.....	23·29	21·79	1·50	
5 35	279	.....	23·16	21·79	1·37	
5 40	279	.....	23·30	21·82	1·48	
5 45	275	.....	23·00	21·83	1·17	
5 43	275	.....	23·05	21·87	1·18	
5 50	275	.....	23·00	21·85	1·15	
5 55	275	.....	23·00	21·86	1·14	
6 0	275	.....	22·93	21·91	1·02	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity, of globe, in grains of water at 39°·1	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
275	23·00	1·14	5	274·34	19214·0	1·11	.....	91·62	91·62	497·25
279	23·25	1·45	3	278·27	19201·2	1·42	0·31	97·61	97·30	496·91
281	23·31	1·56	4	280·24	19197·9	1·53	0·42	100·73	100·31	496·83
282	23·47	1·73	3	281·22	19189·9	1·69	0·58	102·31	101·73	496·63
283	23·77	2·11	4	282·20	19174·7	2·06	0·95	103·91	102·96	496·24
284	24·17	2·61	5	283·18	19154·2	2·55	1·44	105·53	104·09	495·71
285	24·88	3·51	4	284·16	19117·8	3·42	2·31	107·17	104·86	494·81
287	26·82	6·03	4	286·13	19018·4	5·98	4·87	110·53	105·66	491·12
291	31·01	11·59	3	290·05	18771·9	11·30	10·29	117·47	107·18	485·91

Experiment 12.—Globe B. Thermometer A. March 24, 1859.

Weight of water introduced = 41·877 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
3 36	295	325	30·94	20·84	10·10	Lamps lighted at 12 o'clock.
3 40	295	.....	31·02	20·81	10·21	
3 45	295	.....	31·03	20·77	10·26	
3 48	295	.....	30·91	20·84	10·07	
3 51	295	.....	30·91	20·89	10·02	
3 54	295	.....	30·96	20·87	10·09	
4 35	295	320	31·02	20·81	10·21	
4 0	291	320	27·00	22·22	4·78	
4 8	291	.....	27·03	22·23	4·80	
4 50	291	.....	26·95	22·20	4·75	
4 55	291	.....	27·03	22·22	4·81	
4 57	291	.....	27·00	22·17	4·83	
5 5	290	.....	26·40	22·43	3·97	
5 10	290	.....	26·42	22·44	3·98	
5 12	290	.....	26·40	22·39	4·01	
5 25	287	.....	25·00	22·84	2·16	
5 26	287	.....	25·04	22·87	2·17	
5 28	287	.....	24·89	22·90	1·99	
5 30	287	.....	25·00	22·83	2·17	
5 35	285	.....	24·55	22·89	1·66	
5 40	285	.....	24·62	22·93	1·69	
5 42	285	.....	24·66	22·98	1·68	
5 43	285	.....	24·67	23·01	1·66	
5 45	285	.....	24·58	23·02	1·56	
5 50	283	.....	24·39	23·07	1·32	
5 53	283	.....	24·43	23·10	1·33	
5 55	283	.....	24·50	23·06	1·44	
5 57	283	.....	24·51	23·06	1·45	
6 0	281	.....	24·36	23·09	1·27	
6 3	281	.....	24·38	23·11	1·27	
6 5	281	.....	24·33	23·11	1·22	
6 36	293	.....	29·56	21·40	8·16	
6 38	293	.....	29·62	21·43	8·19	
6 40	293	.....	29·51	21·40	8·11	
6 45	293	.....	29·52	21·41	8·11	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
281	24·36	1·26	3	280·24	19150·0	1·23	.....	100·73	100·73	458·30
283	24·46	1·39	4	282·20	19144·9	1·36	0·13	103·91	103·78	458·44
285	24·61	1·65	5	284·16	19137·2	1·62	0·39	107·17	106·78	458·25
287	24·98	2·12	4	286·13	19118·1	2·08	0·85	110·53	109·68	457·79
290	26·40	3·98	3	289·07	19045·1	3·88	2·65	115·70	113·05	456·10
291	27·00	4·79	6	290·05	19014·2	4·67	3·44	117·47	114·03	455·34
293	29·55	8·14	4	292·02	18872·3	7·94	6·71	121·11	114·40	451·95
295	30·97	10·14	6	293·97	18780·3	9·88	8·65	124·75	116·10	449·72

Experiment 13.—Globe A. Thermometer B. October 19, 1859.

Weight of water introduced = 42·680 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
1 33	302	339	23·27	12·86	10·41	
1 35	302	.....	23·22	12·86	10·36	
1 37	302	.....	23·26	12·86	10·40	
1 42	302	336	23·25	12·83	10·42	
1 53	299	329	19·97	13·91	6·06	
1 57	299	.....	19·98	13·85	6·13	
2 0	299	.....	19·93	13·84	6·09	
2 5	299	330	19·96	13·85	6·11	
2 8	299	.....	19·89	13·83	6·06	
2 10	299	.....	19·94	13·85	6·09	
2 20	297	.....	17·94	14·27	3·67	
2 25	297	.....	18·00	14·27	3·73	
2 27	297	327	17·90	14·25	3·65	
2 30	297	.....	18·03	14·23	3·80	
2 35	297	.....	17·95	14·24	3·71	
2 43	293	.....	16·44	14·72	1·72	
2 47	293	.....	16·44	14·69	1·75	
2 49	293	.....	16·43	14·73	1·70	
2 51	293	.....	16·47	14·72	1·75	
2 58	289	.....	16·39	14·80	1·59	
3 0	289	.....	16·36	14·82	1·54	
3 5	289	.....	16·40	14·82	1·58	
3 10	289	.....	16·39	14·76	1·63	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.	Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
°	inches.	inches.		°		inches.	inches.			
289	16·39	1·59	4	288·25	18433·8	1·55	.....	114·24	114·24	433·12
293	16·44	1·73	4	292·19	18431·8	1·68	0·13	121·40	121·27	433·08
297	17·96	3·71	5	296·13	18364·7	3·60	2·05	128·92	126·87	431·50
299	19·94	6·09	6	298·09	18268·3	5·91	4·36	132·80	128·44	429·28
302	23·25	10·40	4	301·03	18097·1	10·09	8·54	138·78	130·24	425·41

Experiment 14.—Globe A. Thermometer A. April 6, 1859.

Weight of water introduced =41·069 grains.

Time.	Thermometer.		Cathetometer.		Difference of level of columns.	Remarks.
	In steam.	In oil.	Inner column.	Outer column.		
h m	°	°	inches.	inches.	inches.	
2 10	297	348	31·88	19·40	12·48	Premature.
2 15	297	.....	31·78	19·38	12·40	Premature.
2 18	297	.....	31·50	19·40	12·10	
2 20	297	.....	31·64	19·38	12·26	
2 22	297	.....	31·60	19·38	12·22	
2 24	297	.....	31·79	19·30	12·49	
2 28	297	.....	31·50	19·35	12·15	
2 30	297	.....	31·38	19·50	11·88	
2 45	297	.....	31·25	19·59	11·66	

Summary of Column Determinations.

Thermometer, Fahr.	Cathetometer, inner column.	Difference of level of columns.	Number of determinations averaged.	Temperature, corrected for pressure.	Capacity of globe, in grains of water at 39°·1.	Difference of level of columns, corrected to 32°.	Rise of column from point of maximum descent.
°	inches.	inches.		°		inches.	inches.
.....	23·30	.....	.....	.....	18414	1·5	.....
297	31·52	12·11	7	295·93	18011·2	11·79	10·29

This experiment was arrested whilst incomplete by the breaking of the thermometer.

Pressure of saturated steam, in inches of mercury.	Pressure of steam in globe, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
.....	.....	449·62
128·40	118·11	439·85

Reduction of the preceding Experiments.

The inner column of mercury having attained its maximum point of descent, remains stationary so long as vaporization is going on in both vessels, and then the temperature at which the first decided indication of ascent of the inner column is observed, obviously gives us the maximum temperature of saturation. Thus, for example, in Experiment 2, we should at once fix this temperature at, or nearly at, 244°·71; for at this temperature the inner column of mercury stands about half an inch above the level corresponding to saturation pressure, the differences of level at less temperatures being too small to warrant us in taking them as indications of superheating. But as slight oscillations in this column, arising from accidental changes of temperature or from other causes, might lead us to infer that the steam had arrived at its maximum temperature of saturation before it had actually attained this point, we considered that there would be less chance of

error, if this point were in all cases determined by a reduction taken from observations made at a point of temperature somewhat above that of saturation.

For small ranges of temperature, we may presume that the relation expressed by equation (1) will apply within small limits of error to superheated steam. Let V_1, p_1, t_1 be the specific volume, pressure, and temperature, respectively, of a given weight of steam when superheated; then we find

$$V_1 p_1 - V_2 p_2 = \alpha(t_1 - t_2), \quad \ldots \ldots \ldots \quad (4.)$$

where the constant $\alpha = 74{\cdot}8$ nearly. Moreover, let T_1 be the maximum temperature of saturation of the steam, and V_1 its corresponding specific volume, then, from equation (1), we get

$$V_1 P_1 = V_2 p_2 + \alpha(T_1 - t_2), \quad \ldots \ldots \ldots \quad (5.)$$

and hence

$$P_1 = \frac{V_2 p_2}{V_1} + \frac{\alpha}{V_1}(T_1 - t_2). \quad \ldots \ldots \ldots \quad (6.)$$

Now having given from the Tables of the experiments the values of V_2, p_2, t_2, and taking V_1 as the specific volume at the maximum descent of the mercury, the value of T_1 may be assumed with a near approach to accuracy from the indications in the experiments; then, if the value of P_1 deduced from this assumption coincide with the pressure of saturated steam at that temperature, the maximum temperature of saturation has been rightly assumed. If not, the value of T_1 deduced from the value of P_1 given by the equation may be taken for a second approximation, and so on till the value of P_1 does coincide with the pressure of saturated steam deduced from the experiments of M. Regnault.

The following Table gives the temperature of saturation thus deduced from the preceding experimental Tables, the two highest temperatures of superheating being in most cases assumed as the data for calculation. In one or two cases, where the lower of these two temperatures is manifestly within the limits of imperfect expansion, the reduction from the higher temperature alone has been retained.

The point thus determined (strictly speaking) is the temperature of maximum saturation of the steam, assuming that at this point it retains all its watery vapour in an aëriform state. This ideal point of temperature, it must be observed, will always be a trifle higher than the actual point. As the coefficient α is always small as compared with V_1, the value of P_1, in equation (6.), is not much affected by any possible variations of value which may be given to this coefficient.

TABLE of Results, deduced from the preceding determinations of the maximum temperature of saturation and specific volume of steam, at pressures of from 15 to 70 lbs. per square inch.

Number of Exper.	Maximum temperature of saturation, Fahrenheit.		Pressure of steam, in inches of mercury.		Specific volume of the steam.	Maximum temperature of saturation, Centigrade.	Pressure of steam, in millimetres of mercury.
1.	242°·89 242·92	242°·90	53·60 53·63	53·61	943·12	117°·16	1361·7
2.	244·90 244·74	244·82	55·60 55·44	55·52	908·03	118·23	1410·1
3.	245·42 245·02	245·22	56·08 55·70	55·89	892·54	118·45	1419·6
4.	255·37 255·62	255·50	66·70 66·97	66·84	759·44	124·16	1697·7
5.	263·20 263·09	263·14	76·26 76·13	76·20	649·24	128·41	1935·4
6.	267·35 267·08	267·21	81·71 81·36	81·53	635·30	130·67	2070·8
7.	269·24 269·16	269·20	84·36 84·25	84·20	605·65	131·77	2138·9
8.	274·76		92·23		584·44	134·86	2342·6
9.	273·30		90·08		543·17	134·05	2287·9
10.	279·42		99·60		514·98	137·45	2529·8
11.	282·55 282·61	282·58	104·48 104·60	104·54	497·25	139·21	2655·2
12.	287·49 287·00	287·25	112·82 112·75	112·78	458·30	141·80	2864·6
13.	292·53		122·25		433·12	144·74	3105·1
14.	288·25		114·25		449·62	142·36	2901·9

SECTION II.—*Experiments at Pressures less than that of the Atmosphere.*

As there would be a difficulty in maintaining the copper steam-bath perfectly air-tight when the elasticity of the steam is considerably less than that of the atmosphere, the construction of the apparatus was modified in the following manner:—

The extremity of the stem of the glass globe, passing through the outer tube, had its extremity inserted in a deep mercury-bath, the surface of which was exposed to the pressure of the atmosphere. The elevation of the column of mercury in the globe-stem above the level of the mercury in the bath being taken at different temperatures, and the corresponding elevation of the mercury in the barometer being observed, the difference of these two columns at once gives the elasticity of the vapour in the globe for the corresponding temperature. The maximum temperature of saturation, in this case, takes place at that point where the column of mercury, measuring the elasticity of the vapour in the globe, begins to deviate from the column of pressure measuring the elasticity of saturated steam.

Plate VIII. fig. 1 is a section of the copper boiler and apparatus arranged for the low-pressure experiments. B is the copper boiler, with its cover removed and supported on the strong tripod as before ; *o o* the outer glass tube $1\frac{1}{2}$ inch diameter and 32 inches long, fixed as before in the stuffing-box *s*, but in these experiments open at the bottom,

and after the insertion of the globe A, closed by an india-rubber cork. C C is the large mercury-bath for heating the glass tube, with its lamp *h*, and shade of sheet iron *k*: the globe A rests on a tripod, *n*, in the copper bath, and its stem passing down through the outer tube, is open at bottom in the mercury-bath. To transfer this globe from its place over the basin in which it has been inverted, to form the Torricellian vacuum to the boiler, the cap of india-rubber (fig. 9) is placed over the end. A small block of wood, *x*, fixed by a wedge, slides over the outer tube and carries a double-pointed screw, by which the level of the mercury in the bottom bath could be read off by the cathetometer, the length of the screw being added to the height taken from the upper point. A frame of wood carried the two thermometers *t* and *t'* placed above and below the globe in the copper bath. The boiler was heated by gas-jets, E, as before. The difficulty arising from the retardation of the passage of heat through the outer glass tube, already alluded to, was found in an increased degree in these experiments, owing to the small surface exposed to the heat of the mercury-bath. After the fracture of two or three tubes, which from their large size were very imperfectly annealed, an iron tube, *p*, was cemented to the lower part of the glass, and entirely removed the difficulty. It enabled a violent ebullition to be maintained in the glass tube, if necessary, at more than twenty degrees lower temperature in the mercury than before.

The globes were filled with mercury, inverted, and the water introduced as before.

Capacity of Globe G.

Water introduced =18425 grains at 50° FAHR., this reduced to 39°·1 =18427 grains.

Graduation:	First file mark . .	=18427·0 grains.
	Second file mark . .	=18553·2 grains.
	Third file mark . .	=18679·4 grains.
	Fourth file mark . .	=18805·6 grains.
	Fifth file mark . .	=18931·8 grains.

The utmost care was taken throughout the experiments to prevent the admission of air or any other influence likely to affect the accuracy of the results.

Experiment 1.—Globe G. Thermometers B and C. November 16, 1859.

Weight of water introduced =2·215 grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
4 35	170	170	227	29·28	4·37	24·91
4 40	170	170	222	29·28	4·37	24·91
4 43	170	170	222	29·28	4·37	24·91
4 45	170	170	226	29·28	4·37	24·91
5 20	140	140	227	29·54	4·37	25·17
5 25	140	140	228	29·53	4·37	25·16
5 28	140	140	228	29·56	4·37	25·19
5 30	140	140	228	29·56	4·37	25·19
5 50	136	136	224	29·64	4·34	25·30
5 53	136	136	224	29·71	4·34	25·37
5 55	136	136	225	29·67	4·34	25·33
6 5	133	133	226	30·04	4·34	25·70
6 10	133	133	226	30·06	4·34	25·72
6 15	132	132	228	30·23	4·34	25·89
6 17	132	132	230	30·22	4·34	25·88
6 19	132	132	230	30·22	4·34	25·88

The barometer reading during this experiment (corrected to 32°) was 30·15.

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1	Difference of level of columns, in inches.	Difference of level of columns, corrected to 32°, in inches.	Elastic force of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
132°	3	30·22	18289	25·88	25·42	4·72	4·72	8265·3
133	2	30·05	18297	25·71	25·27	4·87	4·85	8269·2
136	3	29·67	18310	25·33	24·90	5·24	5·25	8275·3
140	4	29·55	18313	25·18	24·75	5·39	5·83	8278·4
170	4	29·28	18322	24·91	24·48	5·66	12·16	8284·4

Experiment 2.—Globe G. Thermometers B and C. November 11, 1859.

Weight of water introduced = 3·455 grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
11 25	190	190	265	26·42	4·77	21·65
11 30	190	190	263	26·42	4·77	21·65
11 35	190	190	267	26·42	4·77	21·65
11 37	190	190	266	26·42	4·77	21·65
11 40	190	190	266	26·41	4·77	21·64
11 55	180	180	270	26·59	4·77	21·82
12 0	180	180	268	26·59	4·77	21·82
12 5	180	180	268	26·59	4·77	21·82
12 20	170	170	276	26·76	4·80	21·96
12 25	170	170	274	26·75	4·80	21·95
12 27	170	170	274	26·76	4·80	21·96
12 30	170	170	270	26·76	4·80	21·96
12 47	160	160	284	26·92	4·80	22·12
12 57	160	160	284	26·92	4·80	22·12
1 15	150	150	280	28·05	4·80	23·25

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
150°	1	28·05	18364·4	23·25	22·91	7·53	7·52	5321·9
160	2	26·92	18402·5	22·12	21·79	8·65	9·61	5333·5
170	4	26·76	18407·9	21·96	21·63	8·81	12·16	5336·1
180	3	26·59	18413·5	21·82	21·49	8·95	15·26	5338·1
190	5	26·42	18420·7	21·65	21·33	9·11	18·99	5341·2

The barometer read from 30·44 to 30·45 during this experiment.

Experiment 3.—Globe G. Thermometers B and C. November 7, 1859.

Weight of water introduced = 3·76 grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr.°	Fahr.°	Fahr.°	inches.	inches.	inches.
1 5	209·9	.....	264	24·26	4·83	19·43
1 20	209·9	209·9	258	24·22	4·83	19·39
1 25	209·9	209·9	260	24·22	4·83	19·39
1 30	206	206·5	268	24·36	4·83	19·53
1 40	206	206·5	271	24·26	4·83	19·43
1 45	206	206·5	.....	24·27	4·83	19·44
1 48	206	206·5	272	24·26	4·83	19·43
1 50	206	206·5	272	24·26	4·83	19·43
2 10	198	198·4	265	24·39	4·82	19·57
2 15	198	198·5	265	24·38	4·82	19·56
2 20	198	198·4	266	24·38	4·83	19·55
2 25	198	198·4	270	24·38	4·82	19·56
2 41	190	190·5	270	24·50	4·82	19·68
2 45	190	190·5	266	24·51	4·82	19·69
2 49	190	190·5	270	24·47	4·82	19·65
3 2	180	180·4	268	24·67	4·82	19·85
3 8	180	180·4	268	24·67	4·82	19·85
3 11	180	180·4	268	24·67	4·82	19·85
3 25	170	170·4	273	24·84	4·82	20·02
3 30	170	170·4	268	24·82	4·82	20·00
3 33	170	170·4	269	24·82	4·82	20·00
3 50	160	160·1	270	25·03	4·82	20·21
3 55	160	160·1	270	25·00	4·82	20·18
4 0	160	160·1	260	25·00	4·82	20·18
4 17	155	155·1	280	25·93	4·82	21·11
4 25	155	155·1	285	25·95	4·82	21·13
4 27	155	155·1	280	25·93	4·82	21·11
4 30	155	155·1	280	25·90	4·82	21·08
4 35	155	155·1	280	25·94	4·82	21·12
4 41	155	155·1	280	25·95	4·82	21·13
4 52	157	157·2	280	25·53	4·82	20·71
4 55	157	157·2	280	25·52	4·82	20·70
5 0	157	157·2	280	25·53	4·82	20·71
5 7	159	159·3	280	25·18	4·82	20·36
5 10	159	159·4	280	25·19	4·82	20·37
5 15	159	159·4	275	25·18	4·82	20·36
5 25	160	160	276	25·07	4·82	20·25

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
155°·0	6	25·93	18447·2	21·11	20·86	8·52	8·51	4911·9
157·1	3	25·53	18460·7	20·71	20·46	8·93	8·96	4915·7
159·2	3	25·18	18472·4	20·36	20·12	9·28	9·42	4918·7
160·0	4	25·02	18477·9	20·20	19·97	9·32	9·61	4920·2
170·2	3	24·82	18484·5	20·00	19·76	9·61	12·21	4922·6
180·2	3	24·67	18489·6	19·85	19·60	9·77	15·31	4924·9
190·2	3	24·49	18495·8	19·67	19·42	9·94	19·06	4927·0
198·2	4	24·38	18499·3	19·56	19·31	10·04	22·59	4928·4
206·2	5	24·28	18502·7	19·45	19·20	10·14	26·67	4930·0
209·9	2	24·22	18504·7	19·39	19·14	10·21	28·69	4930·7

The barometer read from 29·34 to 29·40 during this experiment.

Experiment 4.—Globe G. Thermometers B and C. November 12, 1859.

Weight of water introduced = 4·985 grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
1 0	211	211	280	21·54	4·45	17·09
1	211	211	285	21·54	4·45	17·09
1 25	190	190	285	21·96	4·45	17·51
1 30	190	190	285	21·96	4·45	17·51

At this point progress was stayed by the cracking of the outer tube.

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
170°	.....	.....	18529	17·90	17·98	12·16	12·16	3722·6
190	2	21·96	18516	17·51	17·26	12·88	18·99	3720·9
211	2	21·54	18508	17·09	16·84	13·30	29·41	3720·3

The barometer (corrected to 32° Fahr.) read during this experiment 30·14 inches.

Experiment 5—Globe G. Thermometers B and C. November 14, 1859.

Weight of water introduced =5·000 grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
4 40	200	200	225	21·87	4·38	.....
4 45	200	200	226	21·82	4·38	.....
4 50	200	200	222	21·60	4·38	17·22
5 0	200	200	224	21·60	4·38	17·22
5 3	200	200	224	21·60	4·38	17·22
5 22	180	180	226	22·00	4·38	17·62
5 25	180	180	225	21·99	4·38	17·61
5 27	180	180	225	21·98	4·38	17·60
5 30	180	180	225	21·98	4·38	17·60
5 40	170	170	226	22·57	4·38	18·19
5 45	170	170	224	22·61	4·38	18·23
5 48	170	170	225	22·59	4·38	18·21
5 50	170	170	225	22·58	4·38	18·20
5 53	170	170	226	22·58	4·38	18·20
6 5	168	168	227	23·11	4·38	18·73
6 8	168	168	227	23·12	4·38	18·74
6 10	168	168	227	23·18	4·38	18·80
6 13	168	168	227	23·15	4·38	18·77
6 15	168	168	.....	23·18	4·38	18·80
6 18	168	168	.....	23·15	4·38	18·77

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass,
168°	6	23·15	18529·0	18·77	18·45	11·61	11·61	3711·3
170	5	22·60	18547·5	18·21	17·91	12·15	12·16	3715·1
180	4	21·99	18557·9	17·61	17·29	12·77	15·26	3717·6
200	3	21·69	18581·0	17·22	16·88	13·18	23·45	3723·3

The barometer (corrected to 32° FAHR.) read during this experiment 30·06 inches.

Experiment 6.—Globe G. Thermometers B and C. November 17, 1859.

Weight of water introduced $=2{\cdot}215+3{\cdot}20=5{\cdot}415$ grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
11 18	200	200	222	20·50	4·35	16·15
11 21	200	200	226	20·51	4·35	16·16
11 25	200	200	226	20·50	4·35	16·15
11 27	200	200	226	20·50	4·35	16·15
11 30	200	200	226	20·49	4·35	16·14
11 45	180	180	228	20·89	4·35	16·54
11 48	180	180	226	20·90	4·35	16·55
11 50	180	180	226	20·91	4·35	16·56
11 53	180	180	226	20·91	4·35	16·56
11 55	180	180	228	20·90	4·35	16·55
12 10	174	174	228	21·31	4·35	16·96
12 13	174	174	228	21·31	4·35	16·96
12 16	174	174	227	21·35	4·35	17·00
12 19	174	174	226	21·33	4·35	16·98
12 24	174	174	229	21·41	4·35	17·06
12 30	174	174	230	21·35	4·35	17·00
12 44	169	169	226	22·71	4·33	18·38
12 48	169	169	225	22·70	4·33	18·37
12 52	169	169	225	22·72	4·33	18·39
12 55	169	169	225	22·76	4·33	18·43
12 58	169	169	225	22·70	4·33	18·37
1 0	169	169	228	22·76	4·33	18·43

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem.	Capacity of globe, in grains of water at 39°·1, in inches.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 39°·1, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
169°	6	22·72	18542·1	18·39	18·13	11·88	11·88	3429·4
174	6	21·34	18588·5	16·99	16·73	13·28	13·33	3438·1
180	5	20·90	18605·8	16·55	16·29	13·72	15·26	3441·8
200	5	20·50	18622·4	16·15	15·87	14·14	23·45	3445·2

The barometer (corrected to 32°) read 30·01 inches.

Experiment 7.—Globe G. Thermometers B and C. November 8, 1859.

Weight of water introduced $=3{\cdot}76+2{\cdot}373=6{\cdot}133$ grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr.°	Fahr.°	Fahr.°	inches.	inches.	inches.
12 35	209·5	209·5	262	17·75	4·88	12·87
12 41	209·5	209·5	265	17·75	4·88	12·87
1 0	190	190	263	18·30	4·88	13·42
1 5	190	190	268	18·27	4·88	13·39
1 12	190	190	268	18·27	4·88	13·39
1 22	186	186	268	18·42	4·88	13·54
1 30	186	186	260	18·42	4·88	13·54
1 40	182	182	262	18·66	4·88	13·78
1 46	182	182	260	18·66	4·88	13·78
1 50	182	182	260	18·66	4·88	13·78
2 10	178	178	270	19·70	4·88	14·82
2 15	178	178	270	19·61	4·88	14·73
2 20	178	178	270	19·68	4·88	14·80
2 27	178	178	260	19·72	4·88	14·84
2 40	181	181	265	18·95	4·88	14·07
2 45	181	181	265	18·97	4·88	14·09
2 50	181	181	263	18·90	4·88	14·02
3 0	182	182	265	18·76	4·88	13·88
3 10	183	183	263	18·77	4·88	13·89

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
178°	4	19·68	18644·5	14·80	14·61	14·80	14·66	3044·8
181	3	18·94	18672·2	14·06	13·85	15·58	15·60	3049·6
182	4	18·68	18680·7	13·88	13·67	15·82	15·90	3051·0
186	2	18·42	18689·3	13·54	13·33	16·01	17·44	3052·6
190	3	18·27	18694·3	13·40	13·20	16·14	18·99	3053·5
209·5	2	17·75	18712·4	12·87	12·65	16·67	28·57	3057·1

Experiment 8.—Globe G. Thermometers B and C. November 15, 1859.

Weight of water introduced $=5{\cdot}00+2{\cdot}15=7{\cdot}15$ grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr. °	Fahr. °	Fahr. °	inches.	inches.	inches.
11 45	211	211	226	15·85	4·47	11·38
11 51	211	211	228	15·85	4·47	11·38
11 55	211	211	226	15·82	4·47	11·35
11 58	211	211	227	15·80	4·47	11·33
12 0	211	211	227	15·80	4·47	11·33
12 15	191	191	224	16·40	4·47	11·93
12 20	191	191	223	16·41	4·47	11·94
12 25	191	191	228	16·39	4·47	11·92
12 28	191	191	228	16·41	4·47	11·94
12 30	191	191	228	16·41	4·47	11·94
12 40	186	186	225	17·35	4·47	12·88
12 45	186	186	227	17·35	4·47	12·88
12 48	186	186	227	17·30	4·47	12·83
12 52	186	186	225	17·25	4·47	12·78
12 55	186	186	228	17·30	4·47	12·83
12 57	186	186	228	17·23	4·47	12·76
6 0	186	186	227	17·26	4·47	12·79
1 10	181	181	227	19·28	4·46	14·82
1 15	181	181	226	19·16	4·46	14·70
1 18	181	181	226	19·18	4·46	14·72
1 20	181	181	226	19·18	4·46	14·72

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
181°	4	19·20	18660·7	14·74	14·52	15·61	15·60	2614·2
186	7	17·29	18727·0	12·82	12·62	17·51	17·44	2623·4
191	5	16·40	18756·5	11·93	11·75	18·38	19·43	2627·8
211	5	15·82	18775·7	11·35	11·16	18·97	29·42	2631·2

The barometer read 30·13 inches.

Experiment 9.—Globe G. Thermometers B and C. November 15, 1859.

Weight of water introduced $=7{\cdot}15+1{\cdot}648=8{\cdot}798$ grains.

Time.	Thermometers in water-bath.		Thermometer in mercury.	Cathetometer.		Difference of level of columns.
	B.	C.		Globe-stem.	Mercury-bath.	
h m	Fahr.°	Fahr.°	Fahr.°	inches.	inches.	inches.
4 57	211	211	227	11·56	4·47	7·09
5 0	211	211	227	11·55	4·47	7·08
5 4	211	211	227	11·55	4·47	7·08
5 6	211	211	227	11·55	4·47	7·08
5 17	201	201	227	11·90	4·47	7·43
5 25	201	201	229	11·95	4·47	7·48
5 28	201	201	229	11·95	4·47	7·48
5 30	201	201	231	11·94	4·47	7·47
5 33	201	201	230	11·94	4·47	7·47
5 45	196	196	230	12·79	4·47	8·32
5 50	196	196	228	12·80	4·47	8·33
5 53	196	196	230	12·82	4·47	8·35
5 55	196	196	230	12·79	4·47	8·32
6 15	191	191	230	15·16	4·47	10·69
6 22	191	191	228	15·14	4·47	10·67
6 25	191	191	228	14·95	4·47	10·48
6 27	191	191	227	15·10	4·47	10·63
6 30	191	191	227	15·10	4·47	10·63

Summary of Column Determinations.

Temperature, Fahr.	Number of determinations averaged.	Mean level of column in globe-stem, in inches.	Capacity of globe, in grains of water at 39°·1.	Mean difference of level of columns, in inches.	Mean difference of level of columns, corrected to 32°, in inches.	Pressure of steam in globe, in inches of mercury.	Pressure of saturated steam, in inches of mercury.	Specific volume of steam in globe, corrected for expansion of glass.
191°	5	15·09	18799·8	10·63	10·47	19·69	19·40	2140·6
196	4	12·80	18876·8	8·33	8·20	21·96	21·57	2149·5
201	5	11·94	18906·4	7·46	7·34	22·82	23·94	2152·9
211	4	11·55	18917·1	7·08	6·96	23·26	29·33	2154·5

The barometer read from 30·16 inches to 30·23 inches during this experiment.

Reduced by the same formulæ as before, we obtain the following general Table of Results of the experiments below the atmospheric pressure.

TABLE of Results reduced from preceding Experiments.

Number of experiment.	Maximum temperature of saturation, Fahrenheit.		Pressure, in inches of mercury.		Specific volume of steam.	Maximum temperature of saturation, Centigrade.	Pressure, in millimetres of mercury.
	°	°	inches.	°		°	°
1.	136·85 136·70	136·77	5·36 5·34	5·35	8275·3	58·20	135·9
2.	155·38 155·28	155·33	8·64 8·61	8·62	5333·5	68·51	218·9
3.	159·35 159·35 159·40	159·36	9·45 9·45 9·46	9·45	4920·2	70·75	240·0
4.	170·88 170·96	170·92	12·46 12·48	12·47	3722·6	77·18	316·7
5.	171·52 171·44	171·48	12·63 12·60	12·61	3715·1	77·49	320·3
6.	174·92		13 62		3438·1	79·40	346·0
7.	182·26 182·34	182·30	16·01 16·02	16·01	3051·0	83·50	406·7
8.	188·30		18·36		2623·4	86·83	466·4
9.	198·78		22·88		2149·5	92·65	581·1

SECTION III.—*Generalization of Results.*

As we purpose to extend these experiments to steam of very high pressure, and to institute a distinct series of experiments on the law of expansion of superheated steam, any elaborate generalizations of the results of the present series of experiments would be premature. In the mean time, however, we give the following general summary of results.

On the Relation of Specific Volume and Pressure of Saturated Steam.

Let V be the specific volume of a given weight of saturated steam, at the pressure P, measured by a column of mercury in inches; then

$$V=25{\cdot}62+\frac{49513}{P+{\cdot}72} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.)^*$$

and

$$P=\frac{49513}{V-25{\cdot}62}-{\cdot}72 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

The following Table shows that formula (7.) represents with considerable accuracy the results of our experiments, and also that they are for the most part perfectly consistent with one another.

* These formulæ, expressed in French millimetres instead of English inches, would be

$$V=25{\cdot}62+\frac{1257605}{P+18{\cdot}29} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10.)$$

$$P=\frac{1257605}{V-25{\cdot}62}-18{\cdot}29 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11.)$$

TABLE showing the relation of Density, Pressure, and Temperature of Saturated Steam.

Number of experiment.	Pressure, in inches of mercury. P.	Maximum temperature of saturation. t.	Specific volume from experiment. V.	Specific volume from formula (7.). V.	Proportional error of formula (7.).
1.	5·35	136·77	8275·3	8183	$-\frac{1}{90}$
2.	8·62	155·33	5333·5	5326	$-\frac{1}{762}$
3.	9·45	159·36	4920·2	4900	$-\frac{1}{246}$
4.	12·47	170·92	3722·6	3766	$+\frac{1}{87}$
5.	12·61	171·48	3715·1	3740	$+\frac{1}{149}$
6.	13·62	174·92	3438·1	3478	$+\frac{1}{86}$
7.	16·01	182·30	3051·0	2985	$-\frac{1}{46}$
8.	18·36	188·30	2623·4	2620	$+\frac{1}{874}$
9.	22·88	198·78	2149·5	2124	$-\frac{1}{90}$
1′.	53·61	242·90	943·1	937	$-\frac{1}{157}$
2′.	55·52	244·82	908·0	906	$-\frac{1}{454}$
3′.	55·89	245·22	892·5	900	$+\frac{1}{111}$
4′.	66·84	255·50	759·4	758	$-\frac{1}{759}$
5′.	76·20	263·14	649·2	669	$+\frac{1}{32}$
6′.	81·53	267·21	635·3	628	$-\frac{1}{91}$
7′.	84·20	269·20	605·7	608	$+\frac{1}{304}$
8′.	92·23	274·76	584·4	562	$-\frac{1}{26}$
9′.	90·08	273·30	543·2	545	$+\frac{1}{271}$
10′.	99·60	279·42	515·0	519	$+\frac{1}{128}$
11′.	104·54	282·58	497·2	496	$-\frac{1}{497}$
12′.	112·78	287·25	458·3	461	$+\frac{1}{152}$
13′.	122·25	292·53	433·1	428	$-\frac{1}{86}$
14′.	114·25	288·25	449·6	456	$+\frac{1}{75}$

On the Law of Expansion of Superheated Steam.

Adopting the notation already employed, and putting r for the rate or coefficient of expansion of an elastic fluid at t_1 temperature, we find

$$r=\frac{1}{\varepsilon_1+t_1}=\frac{\frac{V_2p_2}{V_1p_1}-1}{t_2-t_1}, \quad \ldots \ldots \ldots \ldots \quad (9.)$$

where $\frac{1}{\varepsilon_1}$ represents the rate of expansion at zero of temperature. In the case of air $\frac{1}{\varepsilon_1}=\frac{1}{459}$, so that at 212° the rate of expansion $r=\frac{1}{459+212}=\frac{1}{671}$, and so on to other cases.

This formula is strictly true for all perfectly elastic fluids such as air; and if the intervals (t_2-t_1) and (p_2-p_1) are small, it will give, with a near approach to truth, the rate of expansion of any imperfectly elastic fluid, such as superheated steam.

The following Table gives the value of the coefficient of expansion of superheated steam taken at different intervals of temperature from the maximum temperature of saturation.

TABLE showing the Coefficient of Expansion of Superheated Steam.

Number of experiment.	Maximum temperature of saturation.	Temperatures between which the expansion is taken.		Coefficient of expansion of steam.	Coefficient of expansion of air.
1.	136°·77	140° ,	170°	$\frac{1}{593}$	$\frac{1}{599}$
2.	155·33	160 ,	190	$\frac{1}{556}$	$\frac{1}{619}$
3.	159·36	159·36,	170·2	$\frac{1}{150}$	$\frac{1}{618}$
		170·2 ,	209·9	$\frac{1}{624}$	$\frac{1}{629}$
5.	171·48	171·48,	180	$\frac{1}{200}$	$\frac{1}{630}$
		180 ,	200	$\frac{1}{604}$	$\frac{1}{639}$
6.	174·92	174·92,	180	$\frac{1}{190}$	$\frac{1}{634}$
		180 ,	200	$\frac{1}{637}$	$\frac{1}{639}$
7.	182·30	182·3 ,	186	$\frac{1}{230}$	$\frac{1}{641}$
		186 ,	209·5	$\frac{1}{630}$	$\frac{1}{645}$
8.	188·30	191 ,	211	$\frac{1}{604}$	$\frac{1}{650}$
1′.	242·9	243 ,	249	$\frac{1}{517}$	$\frac{1}{702}$
4′.	255·5	257 ,	259	$\frac{1}{392}$	$\frac{1}{716}$
		257 ,	264	$\frac{1}{600}$	$\frac{1}{716}$
6′.	267·21	268 ,	271	$\frac{1}{210}$	$\frac{1}{727}$
		271 ,	279	$\frac{1}{640}$	$\frac{1}{730}$
7′.	269·2	271 ,	273	$\frac{1}{232}$	$\frac{1}{730}$
		273 ,	279	$\frac{1}{551}$	$\frac{1}{733}$
9′.	279·42	283 ,	285	$\frac{1}{298}$	$\frac{1}{742}$
		285 ,	289	$\frac{1}{533}$	$\frac{1}{744}$
13′.	292·53	297 ,	299	$\frac{1}{281}$	$\frac{1}{756}$
		299 ,	302	$\frac{1}{638}$	$\frac{1}{758}$

The results recorded in this Table distinctly show that, for temperatures within about ten degrees from the maximum temperature of saturation, the rate of expansion greatly exceeds that of air, whereas at higher temperatures from this point the rate of expansion approaches that of air; thus, for example, in Experiment 6, between the temperatures of 174°·92 and 180°, the coefficient of expansion is $\frac{1}{190}$, that is, about three times that of air; whereas between the temperatures of 180° and 200° the coefficient of expansion is very nearly the same as that of air, and so on in other cases. At temperatures somewhat removed from the maximum temperature of saturation, the coefficient of expansion in the high-pressure experiments is decidedly greater than that of air, whereas in the low-pressure experiments it does not greatly differ from that of air. The mean of ε_1 in the latter case $=\frac{1}{7}(453+406+467+424+457+444+413)=438$, whilst for air this constant is 459.

Hence it appears that, as the steam becomes more and more superheated, the coefficient of expansion approaches that of a perfect gas, but that at and near to the maximum temperature of saturation the coefficient of expansion greatly exceeds that of a perfect gas.

Explanation of the Plates.

PLATE VII.

Represents the apparatus for the experiments on the density of steam detailed in Section I.

Fig. 1. Elevation showing the general arrangement of the apparatus, the copper boiler B, gauge G, thermometer *t*, oil-bath C, inner and outer tubes forming the saturation-gauge *o*, *i*, cathetometer *ff*.

Fig. 2. A corresponding vertical section, and

Fig. 3. A plan.

PLATE VIII.

Fig. 1. Represents the apparatus for the experiments in Section II., shown in a vertical section: B copper boiler, *t*, *t'* thermometers, A the globe of glass containing the weighed portion of water, C the lower mercury-bath, *x* double-pointed pin for reading the lower mercury level, *h* lamp, and *e*, *e* gas-jets.

Fig. 2. Represents the cathetometer with its vernier and telescope.

Fig. 3. Represents the vernier and thumbscrew of the cathetometer seen on the other side.

Fig. 4. The glass globe, after the formation of the Torricellian vacuum, arranged with its cap *k*, supported by an india-rubber band for insertion in the boiler for one of the experiments at the higher pressures.

Fig. 5. A section of the cap and globe-stem of fig. 4, showing the platinum wire, &c.

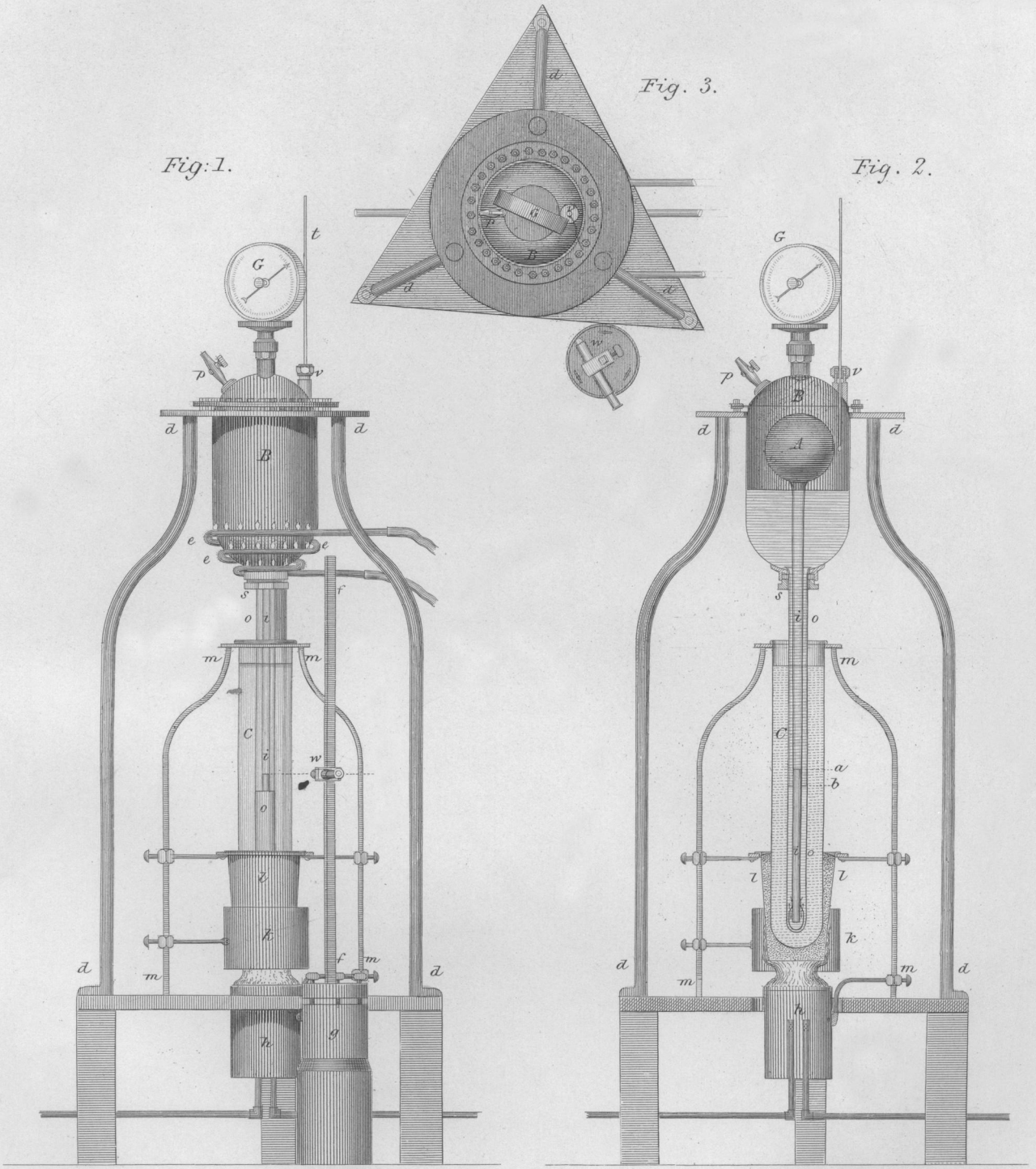
Fig. 6. Different-sized globules for containing weighed portions of water.

Fig. 7. Cup and filled globule ready for transference to the glass globe.

Fig. 8. Bottom of the globe-stem arranged for a transference to the boiler for a low-pressure experiment; the india-rubber cap *c* is removed during the experiment.

PLATE IX.

A diagram in which the relation of temperature and specific volume of steam is represented in a curve, the ordinates of which represent the increments of temperature, and the abscissæ the increments of specific volume: the marks (×) indicate points determined experimentally, and the three curves the relations of specific volume and temperature as given by the common formula derived from the gaseous laws, by Mr. Rankine's formula, and by formula (7.), page 219, of this paper derived from our experiments.



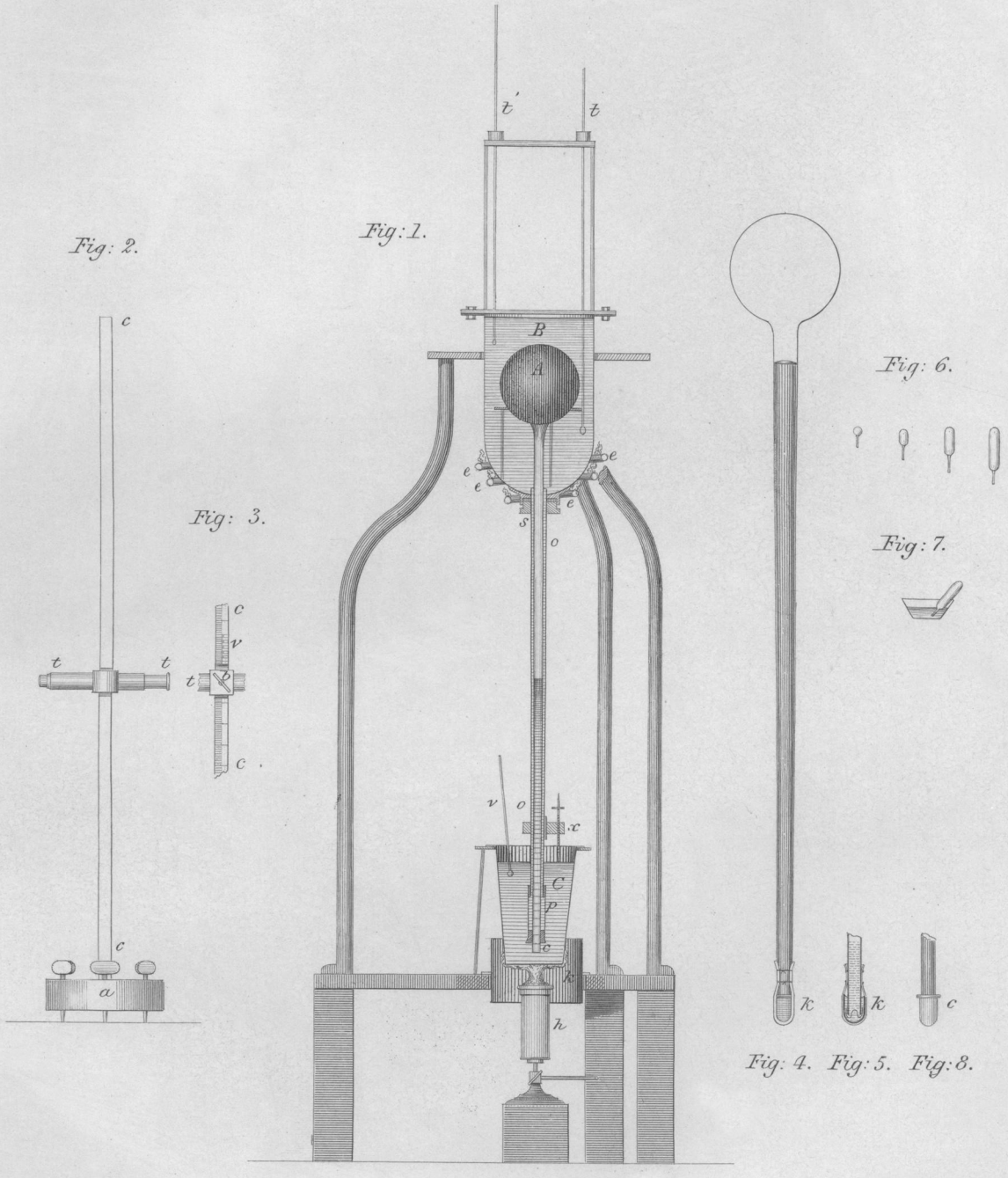
APPARATUS

FOR EXPERIMENTS ON THE DENSITY OF STEAM AT PRESSURES

FROM 15 TO 70 LBS. PER SQ. IN.

Scale 1 inch to a foot

J. Basire, sc.



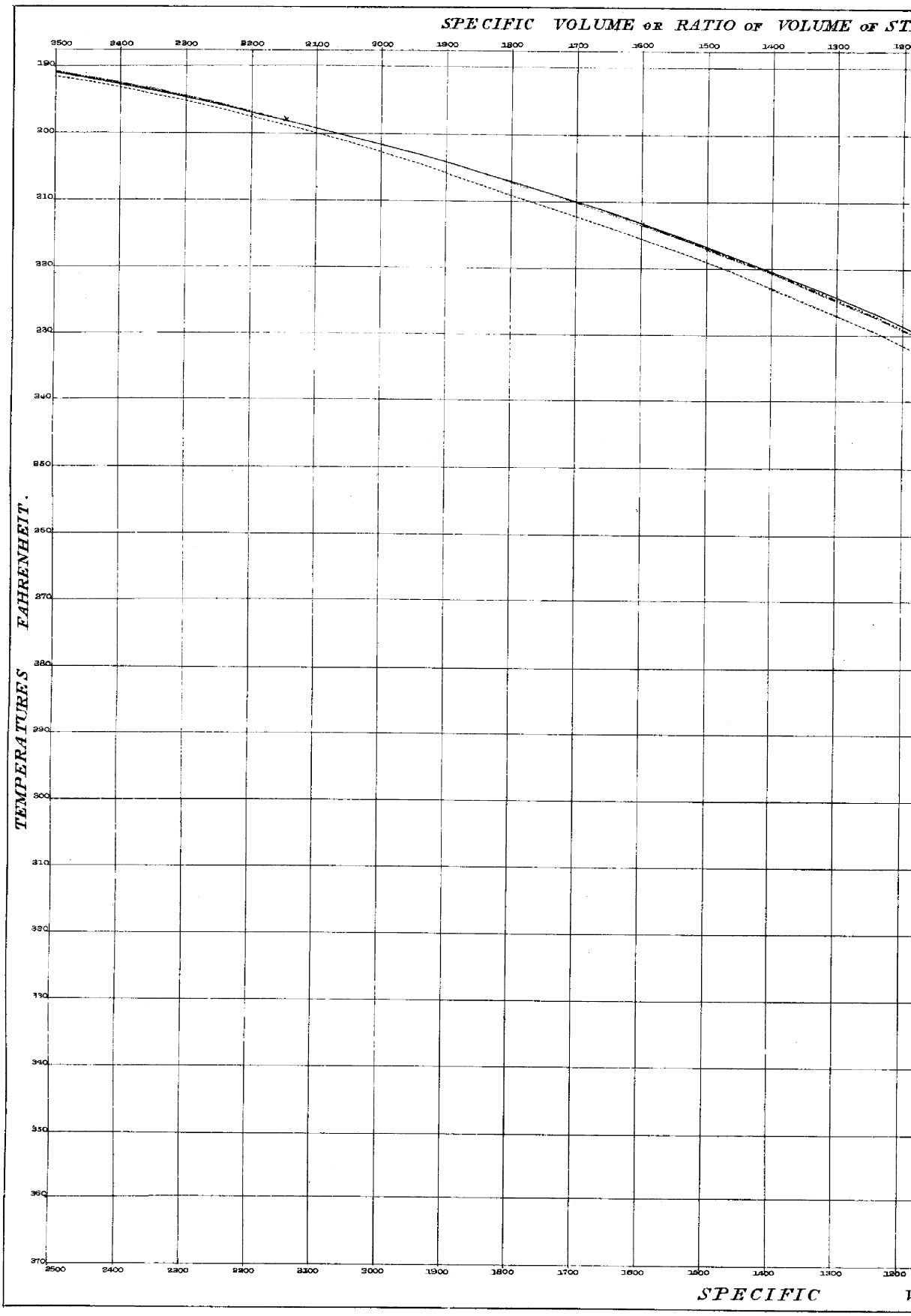
APPARATUS

FOR ASCERTAINING THE DENSITY OF STEAM

AT PRESSURES BELOW THAT OF THE ATMOSPHERE

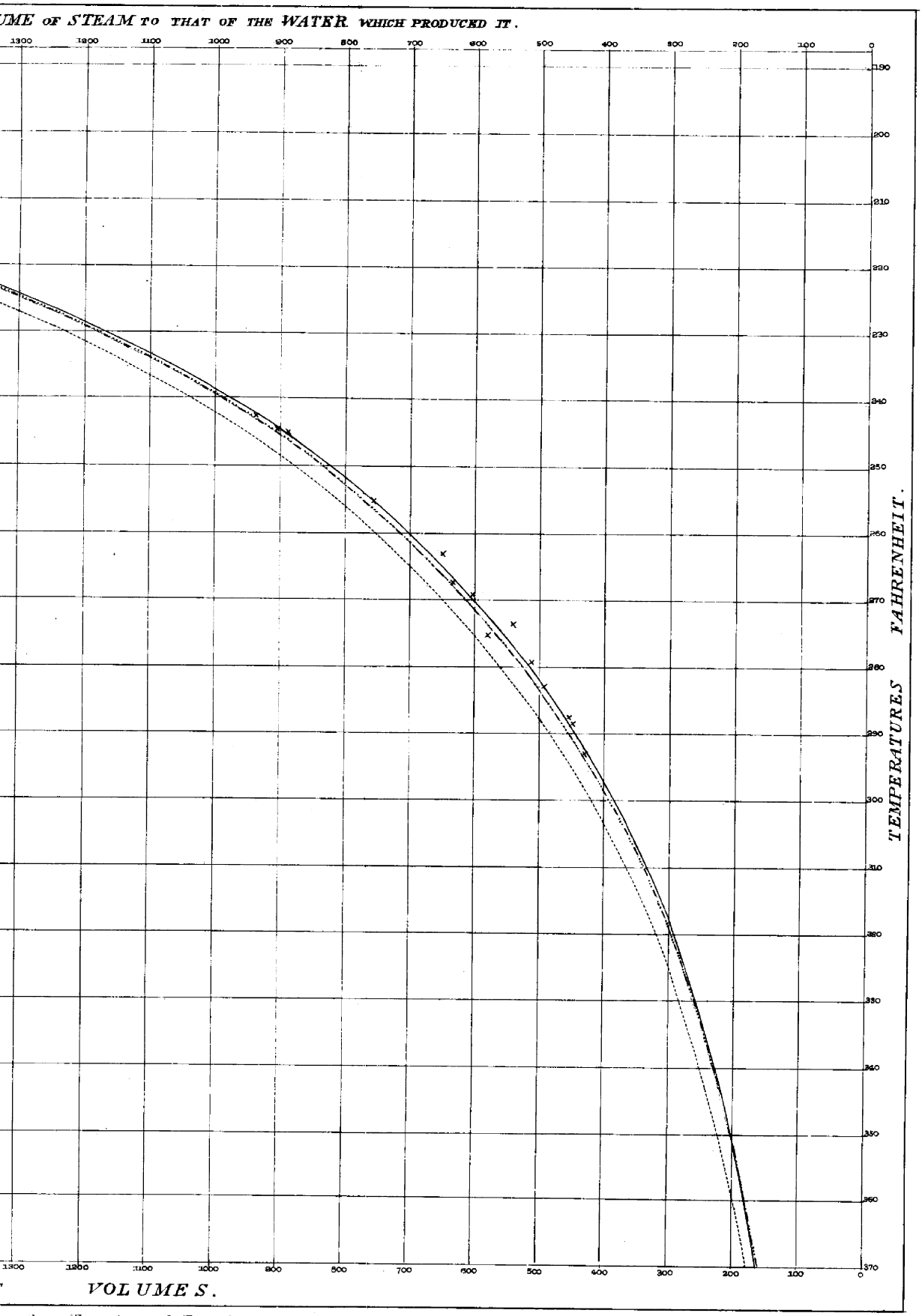
Scale 1. inch to a foot.

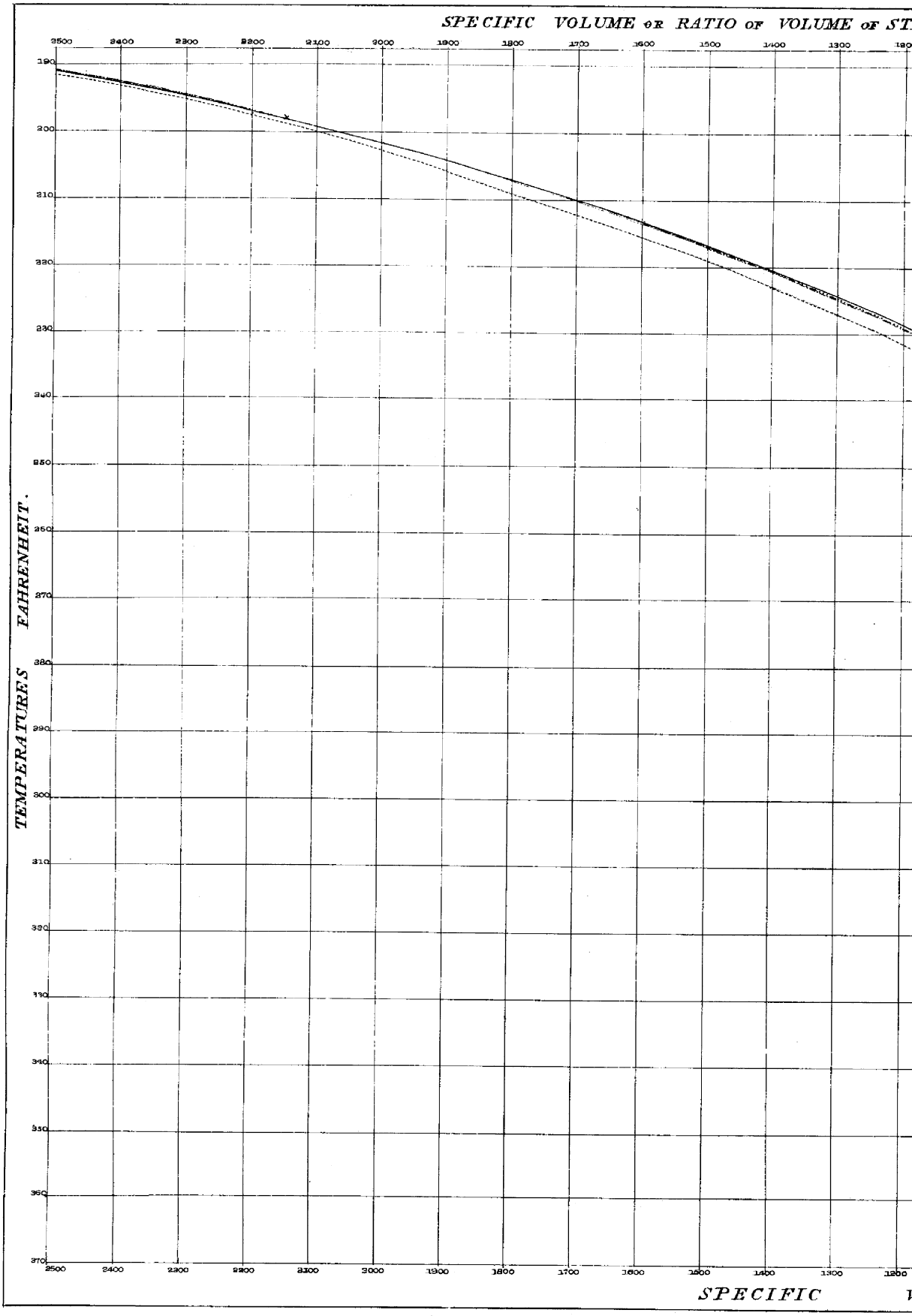
J. Basire, Sc.



Curve derived from Gaseous Formula ..... Curve from Ex

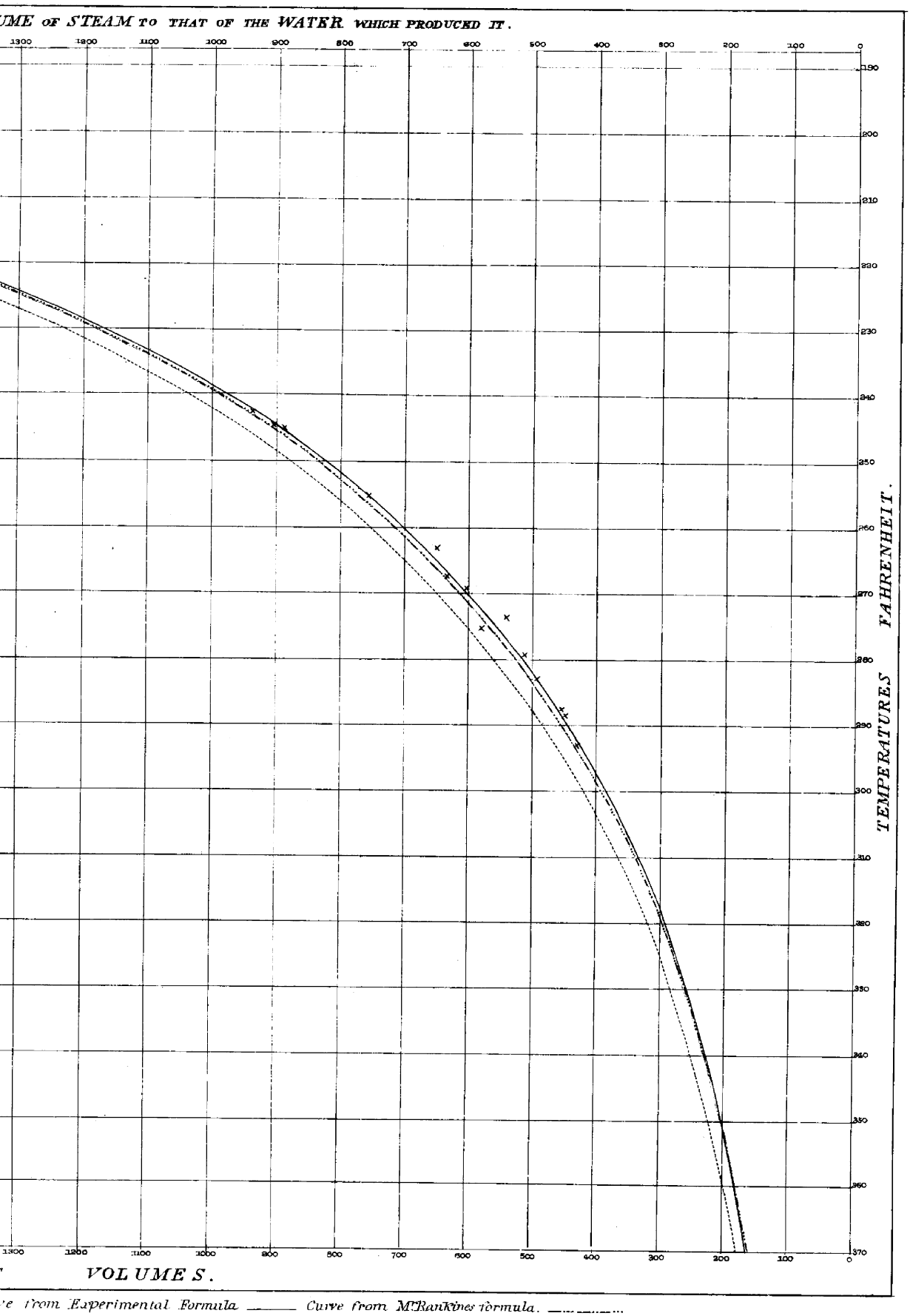
Note. This Plate does not include the Experiments at Low Temper


UME OF STEAM TO THAT OF THE WATER WHICH PRODUCED IT.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
TEMPERATURES FAHRENHEIT.
VOLUMES.
e from Experimental Formula
Curve from Mr. Rankines formula.
t Low Temperatures
The Experiments are marked ×



Curve derived from Gaseous Formula..... Curve from Exp

Note. This Plate does not include the Experiments at Low Temper



e from Experimental Formula ——— Curve from Mr. Rankines formula. —·—·—·—

t Low Temperatures. The Experiments are marked ×